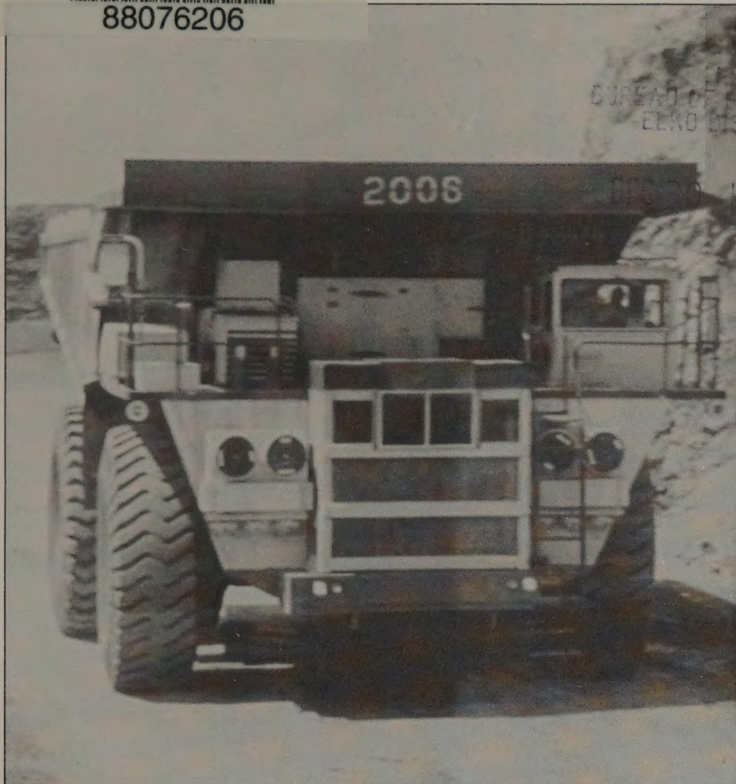

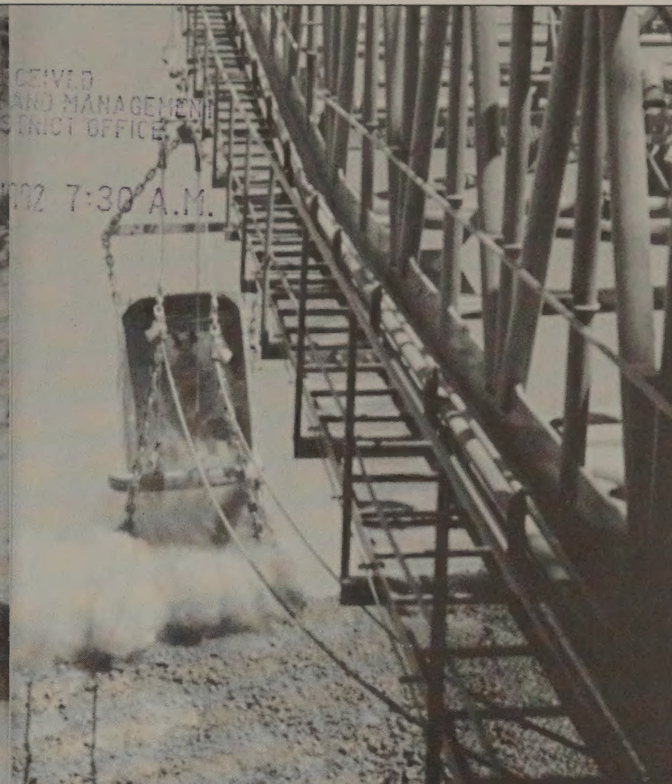

MINING AND QUARRYING TRENDS IN THE METALS AND INDUSTRIAL MINERALS INDUSTRIES

By R. Lindsay Mundell and Steven J. Schatzel

1990

U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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U.S.
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MINES

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Director

November 1992

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COVER PHOTO:
A diesel-powered haulage truck and dragline operating at a surface coal mine in the Western United States.

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MINING AND QUARRYING TRENDS IN THE METALS AND INDUSTRIAL MINERALS INDUSTRIES

By R. Lindsay Mundell and Steven J. Schatzel

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MINING HIGHLIGHTS

In the first half of 1990, lessening of cold war tensions was welcome. But Iraq's invasion of Kuwait in August led to the Persian Gulf War in January and February 1991. The subsequent oil shock contributed to a dampening of the U.S. economy, and the U.S. gross national product rose only 0.9% to \$5,463 billion (U.S. billion = 10^9).

The buildup of military forces in the Persian Gulf area focused greater attention not only on petroleum but also on other strategic materials. The U.S. Department of Defense continued to review stockpile goals and upgrade several mineral materials. In addition, the U.S. Bureau of Mines continued to maintain the standby Emergency Minerals Administration. After the Defense Production Act, which authorizes priorities, allocations, and supply expansion, lapsed on October 20, 1990, the Selective Service Act of 1967 became the authority to ensure that orders of the Armed Forces and defense atomic energy programs were given priority treatment.

Imports of crude and refined petroleum, costing \$61 billion, increased 2% to 3 billion barrels (bbl). Domestic petroleum production fell 2% to 3.6 billion bbl. In February 1991, a National Energy Strategy was announced to encourage domestic production of fossil fuels and nuclear and renewable energy and to stimulate efficiencies in use. Petroleum supplied about 40% of U.S. energy, and natural gas and coal each supplied about 22%.[1]

Although most nongold metal mining and beneficiation production finished below that of 1988-89, almost all production was at levels well ahead of a few years ago. This fact, together with the reduced lure of gold, might be expected to increase the funds available for exploration and development in the ferrous and base metals sectors.

By January 1991, a general consensus was reached among traders and analysts that base metals prices will weaken through 1991 because of economic recession. In January, the price of copper, so often a general indicator, was at a 29-month low and silver was at a 15-year low.[2]

Experts speculate that over the next few years the international mining industry will be dominated by three issues: increasingly widespread environmental concerns; a change in the balance of activity between precious-metals and base-metals operations; and the impact of newly generated base metal demand from Eastern Europe.

Production Overview

Total processed nonfuel mineral materials produced in the United States during 1990 were valued at approximately \$310 billion, essentially unchanged from that of 1989. However, metals from U.S. ores rose 3% over those of 1989 to \$12.5 billion, and industrial minerals rose 5% over those of 1989 to \$20.9 billion. Recycled scrap, largely steel and aluminum, rose a tremendous 50% over that of 1989 to \$15 billion.

Steel production—a major consumer of many minerals—fell 2% to 96 million short tons (st). Iron ore mining fell 8% to 60 million st, 97% of which was pelletized. Net iron ore imports fell 14% to 13 million st. There was no domestic mining of chromium, cobalt, manganese, or nickel.

Primary aluminum smelters operated at capacity, producing 4.4 million st. Some bauxite was mined, but most came from net imports of 14.0 million st. This was supplemented by net imports of 3.1 million st of alumina.

Imports of nonfuel, mineral-based materials were valued at \$44 billion and exports at \$38 billion. Canada, with which the United States has a free-trade agreement and which is a partner in the North American Defense Industrial Base, was a major supplier of many minerals.

Discussions were under way with Mexico, looking toward a possible free-trade agreement that, in turn, might be a prelude to a Western Hemisphere agreement. Concerns about apartheid in the Republic of South Africa continued despite reform efforts. Imports from that country were limited to 10 minerals essential for defense or the economy.

Magnesium and titanium production totaled 165,000 st and 28,000 st, respectively. Copper mine production rose 4% over that of 1989 to 1.7 million st, and refinery production was 2.1 million st. Lead mining rose 18% over that of 1989 to 546,000 st. Primary refined lead production of 435,000 st was supplemented by 865,000 st refined from scrap. Primary slab zinc tonnage of 292,000 st was supplemented by 116,000 st of secondary production and net imports of 496,000 st.

Cement production rose 3% to 80 million st. About 3,400 quarries produced 1.2 billion st of crushed stone, and 5,700 sand and gravel pits produced 920 million st. Nearly 1,100 clay pits produced 49 million st, and 65 gypsum mines produced 18 million st.

Magnesium compounds totaling 700,000 st were produced from brines and seawater. Titanium dioxide pigments totaling 1.1 million st were produced from domestic and imported minerals. Sulfur production totaled 12.4 million st, 32% by the Frasch process. Production of other major nonmetallics included 39 million st of salt, 17 million st of lime, 10 million st of soda ash, and 625,000 st of B_2O_3.

Phosphate rock mining fell 8% to 51 million st, and ammonia rose 3% to 14

million st. Potash mining rose 3% to 1.8 million st of K_2O. Significant quantities of ammonia and potash were imported, but fertilizer exports totaled $4.1 billion.

Gold production edged up to 65 million ounces (oz) worldwide during 1990. This 2% gain over that of 1989 was low in comparison to 6% gains prevailing in recent years. The rankings of the million-oz-per-year producing countries remained unchanged. U.S. mines yielded 9.6 million oz of gold and 64 million oz of silver. About 10% of the gold and 75% of the silver was a byproduct of base metal mining. Approximately 50% of the U.S. gold production was from surface leaching operations. The 1990 average price of $387 per oz was little changed above that of 1989. However, the 1990 price was more volatile than during the previous year. Gold mine openings and expansions were on the decline in 1990.

The gold industry entered a period of economic hardship during 1990. As a result, North American exploration and new mine developments were greatly curtailed. In addition, increasing regulatory burden and pending legislation regarding mineral tenure could drive small miners offshore or out of business. Small miners, ultimately, are responsible for most U.S. mineral discoveries.

Australian output is forecast to drop by 20% per year following imposition of an income tax on gold mining that was effective on January 1, 1991. Output of silver mined in the world, at 469 million oz, was up only 1% over that of 1989. An estimated 60% of newly mined silver is recovered as a byproduct of gold and polymetallic base metal deposits. In 1990, the price briefly slipped below $4 per oz.[3]

Incentive Systems on the Rise

More mining companies used incentive bonus plans as part of their wage systems in 1990. A survey by Mining Cost Service of Spokane, WA, found that of the 156 mines responding to inquiries, a remarkable 42% reported using some sort of incentive bonus plan in 1990. This represents the continuation of a steady growth pattern in the use of incentive systems by the mining industry. In 1987, only 20% reported having a bonus system in place compared with 23% in 1988 and 35% in 1989. According to the survey, metal mines were the largest users of incentive bonus plans this year. About 33% of the responding coal mines and 25% of the responding industrial mineral mines also had bonus systems in place. In the metal mines, production was the most commonly mentioned incentive factor. Development advance, safety, ore grade, cost saving, profits, commodity prices, housekeeping, and length of service were also mentioned. Attendance, production, safety, and profits were all mentioned by industrial mineral mines. Of the 24 industrial mineral mines responding, 21 reported wage increases ranging from 1% to 13%. The remaining three reported no change. Forty of the 66 metal mines reported wage increases ranging from 1% to 18%. No metal or industrial mineral mines reported wage decreases in 1990.[4]

Reclamation Bonds

New Federal reclamation bonding requirements were not expected to have a significant impact on large mining concerns, but might put smaller companies and prospectors out of business. The new policy was drafted to ensure that reclamation bonds are posted, but in a manner that companies would not pay both Federal and State bonds. Several mining company officials said the new policy will burden small miners who may not be able to afford bonds. Many States currently do not require bonds for small prospectors.[5]

Soviets Open Mineral Deposits to Joint Ventures

Because the U.S.S.R. does not have sufficient funds to develop many of its natural resources, the Soviets were forced to pare mining activities. In an effort to raise much-needed hard currency, the U.S.S.R. prepared a list of 100 mineral deposits made available to foreign companies for joint ventures. This marked the first large-scale effort by the Soviets to encourage joint ventures in mining.

The U.S.S.R.'s joint-venture master plan included proven deposits of aluminum, chromium, gold, iron, lead, manganese, nickel, silver, tungsten, and zinc. The Soviet Ministry of Geology explored the deposits and determined that they are minable.[6]

The Soviet North East Gold Mining Association and Bering Straits Trading Co. awarded a contract for a joint venture between Cominco Engineering Services Ltd. of Vancouver, British Columbia, Canada, and Watts, Griffis and McOuat, geologists and engineers, of Toronto for a planned silver recovery system with a capacity of 1 million st of ore annually. Plans call for construction of a plant in Dukat, northeast of Magadan in the extreme northeast U.S.S.R.[7]

LEGISLATION AND GOVERNMENT ACTIONS

Pending Legislation

Efforts were put forth in 1990 to amend the General Mining Law of 1872. House bill S. 1126 was introduced in June 1989. Hearings were held in June 1989 and again in September 1990. As introduced, the bill would withdraw certain types of lands presently open to mineral entry. Jurisdiction over Forest Service lands would move to the Department of Agriculture. It would eliminate exploration or development by joint ventures, partnerships, and multiple mineral development within the same operating area unless under a single operator and would eliminate different types of mining operations in the same area. It would also eliminate lode and placer distinction as well as larger sized claims currently allowed for placers.

All prospectors would be required to notify the land management agency before initiating mineral exploration. The claim recordation fee would be raised to $100 per claim. Mining claims would be for exploration purposes only and would be limited to 20 acres. Jurisdiction would be divided among the Departments of Agriculture and Interior, who would have total discretion to deny the application without appeal. The exploration claim would be void after 10 years unless the locator applied for a mineral patent.

Prior to any mineral development or production, the locator of an exploration claim would be required to have an approved exploration plan and reclamation plan and would have to submit an application for mineral patent. A hard-rock mineral deposit capable of commercial development would have to exist on the property, and a mining and reclamation plan would have to be approved before a mineral patent could be issued. Such a patent would not, however, convey possessory title to the minerals. The patent would be void if mineral production did not begin within 15 years.

Exploration claims would require annual diligence, or in lieu of payments, of $50 per acre until production began. Patents would require annual diligence from $100 per acre for the first 5 years to $300 per

acre during years 10 through 15. Once production commences, an 8% overriding royalty on production would be assessed. The bill also provides for payment of an annual $100 "holding fee" for each exploration claim or mineral patent and a $5 per acre surface-use fee.

All mined areas would have to be reclaimed and restored to a condition supporting the original use prior to mining. This work would have to be done with concurrent reclamation when feasible. Bonding sufficient to ensure complete and timely reclamation would be required for exploration claims and mineral patents. Further, the bill requires that land-managing agencies address mining and exploration activities in their land use plans and provide conditions and restrictions on these activities.

The bill also addresses the conversion of existing claims. It would eliminate the right to patent claims located under the 1872 Mining Law and would take away valid existing rights. Further, it would require that within 3 years existing claimholders either relocate their claims under the terms of the new law, with some exceptions, or maintain them by performing assessment work fixed at $5,000 per mining claim per year.

House of Representatives bill 3866 was introduced in January 1990. A hearing was held in September 1990. As introduced, the bill established procedures to locate and record mining claims. It eliminated distinctions between lode and placer claims and claims for "uncommon varieties." It would move jurisdiction over minerals on Forest Service lands to the Department of Agriculture. Mill sites and tunnel sites would be eliminated.

Claims would be 40 acres and would have to conform to the public land survey, where possible. Extralateral rights would be eliminated. The legal description in the notice of location would supersede the physical boundaries on the ground. A claimholder who relinquishes a claim or fails to maintain all requirements would not be permitted to file a new claim on the same ground for 6 months.

All mining activities on mining claims would have to prevent unnecessary degradation and minimize adverse environmental impacts on surface resources. A plan of operation would be required for prospecting and exploration. Adequate financial or other guarantees would be required to ensure reclamation, and the Secretaries of Agriculture and Interior would establish reclamation standards. Land use plans would be required to include numerous specific requirements to ensure protection of nonmineral values. The bill also authorizes quarterly compliance inspections by the Office of Surface Mining and Regulation Enforcement.

A mining claim would be valid when the rental fee requirements and the diligence expenditures or the in-lieu-of-payment were met. The annual rental fee would be $1.50 per acre prior to approval of a mining plan and $5.00 per year after approval. Diligence would be required on a 5-year incremental scale ranging from $20 per acre in the first 5 years to $160 per acre after the 15th diligence year following recordation of the claim. Payments in lieu of diligence could not be made until the 6th year; these payments would also be graduated, ranging from $20 per acre in the 6th through 10th years to $80 after the 15th year. The bill further directs the appropriate Secretary to establish user fees to reimburse the United States for expenses incurred under the legislation. Failure to submit payments or file a diligence affidavit would void the claim.

Patenting of existing mining claims would be eliminated. Unpatented mining claims located under the Mining Law of 1872 would have to be converted to the new system within 3 years. Unconverted claims would be null and void.

The bill also directs that all monies received from rental fees collected be put into a fund for the reclamation and restoration of land and water resources adversely affected by past mineral mining.

The Resource Conservation and Recovery Act

In April 1991, the comprehensive Resource Conservation and Recovery Act (RCRA) bill (S. 976) was introduced. Although mine and mineral-processing wastes were not directly addressed in the bill, several provisions of the bill may still have an impact on the management of mines or mineral-processing facilities, such as requirements affecting recycling, secondary materials, and pollution-prevention activities.

EPA Activities—Mining- and Mineral-Processing Wastes

In May 1988, the U.S. Environmental Protection Agency (EPA) released a document that outlined an approach to manage noncoal mining wastes and materials, referred to as "Strawman I," for public comment. In May 1990, EPA issued "Strawman II," incorporating comments and responding to raised issues. After court action, EPA was ordered to define large-volume, low-hazard wastes, and a final ruling was published January 23, 1991. EPA established that the temporary exemption from subtitle C requirements, established by the exclusion for mineral-processing wastes, was limited to 20 mineral-processing wastes, including (1) slag from elemental phosphorus production, and (2) phosphogypsum and phosphoric acid process wastewater. If the exclusion is retained, the wastes would be subject to regulation under the Resource Conservation and Recovery Act subtitle D and as solid wastes.

The mine waste regulatory program, as currently viewed by EPA, will be one in which the States have the lead role and will be responsible to develop, oversee, and enforce a mining waste and materials management plan. Consequently, the States will be expected to identify a lead agency; incorporate a multimedia approach that addresses air, surface water, ground water, and soil contamination; and incorporate any necessary permits under the National Pollution Discharge Elimination System (NPDES), the Clean Air Act, and the Underground Injection Control program. To be approved by EPA, the mining waste and materials management plan would need to provide for a State program adequate to meet established technical design criteria and performance standards.

Mineral-processing wastes are being addressed separately by EPA. The number of processing wastes afforded protection by the Bevill amendment from hazardous waste regulation under RCRA subtitle C was reduced. In EPA's July 1990 Report to Congress, the Agency concluded that no more than 4 of the 20 conditionally exempted wastes under Bevill needed to be regulated as a hazardous waste. The findings of the report will be the basis of a final regulatory determination. All other mineral-processing wastes are now potentially subject to regulation as hazardous wastes under subtitle C of RCRA.

Basel Convention

In March 1990, the United States signed the Basel Convention, an international agreement dealing with the international transboundary movement of hazardous waste. The Basel Convention is intended to put an end to the shipment of hazardous wastes for disposal in other nations,

particularly developing nations. However, the convention could affect the way metal waste and scrap, as well as other recyclable materials, are imported or exported because all of these materials are considered to be hazardous wastes in some countries, particularly in the European Community (EC). Materials that are likely to be affected include metal waste and scrap, scrap batteries, precious-metal wastes and residues, and materials recovered from municipal waste.

Under the Basel Convention, requirements will include advance notification of shipments of hazardous wastes through the Governments of the exporting and importing nations and acceptance of the material by the importing nation. Both the exporting and importing nations are obliged to assure that the handling and disposal of the waste is environmentally sound. Trade in hazardous waste between a nation that is a party to the convention and one that is not will be prohibited, unless the nations enter into a separate agreement that is at least as protective of the environment as is the Basel Convention.

The Basel Convention was submitted to the U.S. Senate for ratification, and legislation was introduced to provide the authority to implement its provisions in the United States. It could take effect as early as 1992.

Ocean Mining Leases Offered

For the first time since the sale of phosporite leases on California's 40-mile (mi) bank in 1963, the U.S. Department of the Interior issued a proposed leasing notice for minerals other than oil, gas, or sulfur on the Continental Shelf. The notice was published by the Minerals Management Service on June 11, 1990, in accordance with new regulations for leasing (30 CFR Part 281) under the authority of the OCS Lands Act of 1953, as amended.

About 150,000 acres is being proposed for leasing to include the right to explore for and recover gold and any other mineral, such as mineral sands, using similar technology. The proposed lease areas are along the boundary of Alaskan State waters 3 mi offshore and adjacent to the city of Nome and the town of Solomon, about 20 mi to the east. Both areas offered are of similar dimension.[8]

Lead-Acid Battery Recycling

Lead-acid battery recycling has been revived in recent years. The primary reason has been relatively high prices for lead scrap and spent batteries. With RCRA and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, looming over the secondary lead industry, they have been quite effective in getting the batteries into the recycling chain. An important factor in this respect has probably been State and local interest in collecting lead batteries by providing incentives; some States are offering $2.00 bounties on spent lead-acid batteries. A further objective is to reduce the number of spent batteries going to landfills and municipal incinerators.

Federal legislation related to the recycling of lead-acid batteries that was introduced in the 101st Congress was not acted upon, but some bills were reintroduced into the 102d Congress. Bill H.R. 870, introduced in February 1991, in particular is essentially written to affect lead-acid battery recycling. The bill would require manufacturers and importers of lead-acid batteries to recycle an equivalent amount of batteries sold. In the case of importers, they would be required to purchase credits from others who recycle batteries. Another bill, S. 391, also introduced in February 1991, is designed to address all issues related to lead in general, with specific provisions for prohibiting disposal in landfills and incinerators.

Another important activity in lead-acid battery recycling is the regulatory negotiation in progress sponsored by the EPA. The regulatory negotiation was established under the Federal Advisory Committee Act (FACA). The committee's purpose is to negotiate issues leading to regulating the recycling of lead-acid batteries under section 6 of the Toxic Substances Control Act (TSCA).

Clean Air Act Amendments

The Clean Air Act Amendments of 1990, signed in November, will likely substantially affect the economics and viability of the minerals industry. For example, coke ovens are specifically mentioned as subject to stringent toxic emission limitations. Most other minerals processing facilities will also be required to limit their emissions of 189 listed air toxics, including such substances as cadmium, chromium, cobalt, lead, manganese, mercury, and nickel compounds. Also, the acid rain provisions of the act will bring about increased electric rates to many mineral producers, in particular to about one-half of the energy-intensive aluminum smelting and ferroalloy-producing industries.

Public Land Use

In 1989-90, Congress considered two bills to set aside areas of the California desert as new national park or wilderness areas. These were S. 11/H.R. 780 (California Desert Protection Act) and H.R. 3460. Both actions would have precluded or limited mineral access in large areas, including the East Mojave National Scenic Area (EMNSA). Neither bill was released from committee by the end of the Congress. At the outset of the 102d Congress in 1990, the California Desert Protection Act was reintroduced.

Potential impacts of the proposed legislation relating to the EMNSA were estimated in a study done by the U.S. Bureau of Mines, entitled "Minerals in the East Mojave National Scenic Area, California" (MLA 6-90, available from the U.S. Bureau of Mines). The study included economic analysis because the proposals raised questions about the profitability of mining in the affected area, as well as the regional economic benefits derived from mining. The study found that 24 deposits in the EMNSA would be profitable to develop under current economic conditions. If all 24 were to be developed, economic benefits would include $3 billion in cumulative production revenues. That development could generate about 2,400 jobs for mines and supporting industries in San Bernardino County, plus jobs in transporting the minerals. The study also included estimates of the impact of proposed withdrawals on employment, personal income, and tax revenues.

Trade Issues

The United States and Mexico continued negotiations begun in late 1989 to eliminate barriers to trade (of goods and services) and investments between both countries. Mexico's foreign investments restrictions prohibit foreign majority ownership of Mexican mines. The United States has no such restrictions against foreign mineral investment. Many issues, including those related to Mexican foreign investment barriers and environmental standards, have to be resolved before both countries can conclude a formal United States-Mexico Free-Trade Agreement.

During 1990, as part of the continuing Uruguay Round of General Agreement on

Tariffs and Trade (GATT) tariff negotiations, the United States sought reductions in Japanese tariffs on processed minerals and metals. U.S. exporters of aluminum products and refined copper faced Japanese tariffs ranging from 5.8% to 12.8% for aluminum products and 7% for refined copper. At the same time, the United States and Japan continued to discuss nontariff trade barriers in both countries during the Structural Impediment Initiative (SII) talks that began in March 1989. The goal of the SII is to eliminate structural trade barriers (i.e., barriers to market access) and thus reduce the imbalance of payments in both countries. U.S. soda ash producers maintain that in 1990, Japanese imports of soda ash were unfairly limited by collusion among Japan's domestic producers. Two U.S. steel producers seeking to bid on nine Japanese Government contracts waited 2 years to be qualified before submitting any bids. In 1990, the Japan Fair Trade Commission drafted new guidelines to open the Japanese market. Japan also announced that in 5 years it would reduce its patent processing time to 2 years, similar to that of the United States.

Two mineral-related trade disputes involving the United States were resolved satisfactorily in 1990. In January 1990, the United States Trade Representative (USTR) negotiated an agreement with the EC. EC member countries agreed not to renew export restrictions on copper scrap that had expired in December 1989. The Copper and Brass Fabricators Council had filed a petition with the USTR charging that the EC had unfairly maintained export controls on copper scrap. After discussions between the United States and the EC failed, both asked GATT to resolve the dispute. The United States argued that there was no shortage of supply or national emergency to justify the EC's export controls on copper scrap. Before the GATT could reach a decision, the USTR and the EC reached an agreement.

In September 1990, the United States and Japan agreed that Japan would create opportunities for U.S.-produced amorphous metals to be marketed in Japan for a 2-year period. Allied-Signal Corp., a U.S. producer of amorphous metal, filed a petition with the USTR requesting an investigation of Japan's business practices. The company felt that with the consent and cooperation of the Japanese government, Japanese steel companies were refusing to enter into licensing agreements on terms with Allied-Signal. In addition, Japanese electric utility companies were refusing to purchase electric power transformers made by Allied-Signal, and Allied-Signal felt that the composition and process patents applied for by Allied-Signal were unfairly delayed (11 and 12 years, respectively). Allied-Signal concluded that the Japanese government had targeted amorphous metals technology for its own use. It was simply using the time until 1993, when the Allied composition patent expired, to develop Japan's own amorphous metals technology while denying U.S.-made amorphous metals access to the Japanese market. Although an agreement was reached, Japan will not grant an extension of Allied-Signal's composition patent when it expires in 1993.

National Defense Stockpile

According to section 3301 of the National Defense Authorization Act for fiscal years 1990 and 1991 (Public Law 101-189, November 29, 1989), the Assistant Secretary of Defense determined that, effective in June, the National Defense Stockpile (NDS) goal for antimony was increased from 36,000 st to 88,500 st.

The Defense Logistics Agency (DLA) announced the awarding of the first in a planned series of contracts to upgrade metal-grade bauxite ore in the NDS to aluminum metal. The contract, awarded to a company headquartered in Pittsburgh, PA, called for the conversion of 243,852 st of bauxite ore to 55,157 st of aluminum ingots. Work on this contract was expected to be completed by September 1992. The Agency also awarded a contract to a domestic company to upgrade some of the beryl ore in the NDS to vacuum-hot-pressed beryllium billets over a 2-year period, beginning in early 1991. The contract also had an option for the Government to purchase an additional 43,000 pounds (lb) of beryllium in 1993 for about $13 million.

The DLA also initiated a number of other actions in June 1990. The Agency approved a reduction in the goal for bismuth in the NDS from 990 st to 480 st. The DLA began sales of excess bismuth from the NDS in August. Requirements for the columbium (niobium) group in the NDS were almost tripled from 4.85 million lb of contained columbium to 12.52 million lb of contained columbium. The Agency revised the goals for both acid-grade and metallurgical-grade fluorspar. The goal for acid grade went from 1.4 million st to 900,000 st. The goal for metallurgical grade went from 1.7 million st to 310,000 st. The Agency also lowered the goal for the battery-grade group from 87,000 to 50,000 st. Accordingly, within that group, the goal for the battery ore subsequently was decreased from 62,000 to 25,000 st, while that for synthetic dioxide remained unchanged. Goals for palladium and iridium were lowered to 147,430 and 5,897 lb, respectively. New goals for rhodium and ruthenium were established at 2,057 and 4.9 lb, respectively. In addition, the Agency accepted sale offers from two of six bidding firms for the DLA to purchase a total of 200,000 lb of tantalum pentoxide contained in tantalum natural minerals and concentrates for the NDS at an average purchase price of $36.81 per lb of contained tantalum pentoxide.

Commodities

Presidential Proclamation 6123, in April 1990, made acid-grade fluorspar from Mexico eligible for preferential tariff treatment under the Generalized System of Preferences, pursuant to title V of the Trade Act of 1974, as amended. Effective July 1, 1990, this material was exempted from duty upon entering the United States. The preferential tariff treatment applies as long as Mexico's share of the import market does not exceed 50% or $89.9 million. In August 1990, the 13.5% ad valorem tariff on imports of metallurgical-grade fluorspar was suspended through December 31, 1992. Imports of both acid-grade and metallurgical-grade fluorspar were down from those of 1989. The largest decrease was for acid grade, which was down more than 23% compared with that of 1989. This was a result of decreased production of chlorofluorocarbons (CFC's) owing to production restraints imposed by the Montreal Protocol and the new excise tax on CFC's.

In June 1990, at a congressional hearing, the Executive Director and two members of the Institute of Scrap Recycling Industries Inc. testified before a subcommittee on the fate of more than 100 mothballed ships that belong to the National Defense Reserve Fleet. Carnegie Mellon's Center for Materials Production conducted a case study of cryogenic scrap preparation to determine if the process is worth looking at again. The world's first dezincing line began commercial operation in Canada. The EPA listed electric furnace dust as hazardous waste and issued regulations requiring dust containing 15% or more zinc

to be processed with the best demonstrated available technology after August 8, 1991.

Changes in Eastern Europe probably would have little impact on the world's metal and scrap industries in the short term. However, for the long term, these changes most likely would have considerable influence. Reportedly, there has been a gradual decline in iron and steel content and growth in the use of other materials in U.S.-built cars. The U.S.S.R.'s Minister of Metallurgy called for a cut in ferrous scrap exports to avoid domestic shortages. The Brazilian Government shut down 20 pig iron producers in May for not reforesting areas cut down to make charcoal.

The principal issue that continued to confront the U.S. slag industry was the proposed Federal regulation that would classify iron and steel slags as solid wastes. In July 1990, the EPA published its required report to the Congress on the 20 mineral-processing waste streams proposed for retention under the Mining Waste exclusion, or the Bevill exclusion, of the RCRA. Blast furnace slag and those steel slags generated from open-hearth and basic oxygen furnaces were among the 20 waste streams proposed.

At midyear, the EPA's "third-third" rule became effective for landfilled process wastes. This rule required pretreatment for most secondary smelter slags at significant cost. However, the industry won a 2-year temporary reprieve to a less strict interim standard on appeal. In October, EPA proposed the "final" lead in drinking water standard, which eventually could result in a required 80% reduction of lead in process effluents and discharges at considerable cost to producers and battery plants. After 2 years of intense study, EPA completed a long-range, multimedia pollution prevention strategy for lead that will result in significantly stricter regulations imposed on both the producing and consuming sectors of the industry over the next several years.

The first stage of EPA's three-stage phaseout of asbestos went into effect in August. The first stage bans the manufacture, import, and processing of asbestos-containing flooring and roofing felt, pipeline wrap, asbestos-cement, corrugated and flat sheet, vinyl asbestos floor tile, and asbestos clothing after August 27, 1990. The sale of these products is banned after August 25, 1992. Stages two and three of the phaseout go into effect on August 25, 1993, and August 26, 1996, respectively.

In August 1990, the EPA, in cooperation with the domestic paint industry, banned the use of mercury in indoor latex paint, citing a risk of poisoning, especially to children, when the paint is used in poorly ventilated areas. The decision also required outdoor latex paint containing mercury to carry a warning label.

In addition, in August 1990, U.S. producers filed a petition with the U.S. International Trade Commission and the U.S. Department of Commerce (DOC) requesting the imposition of antidumping duties on imports of silicon metal from Argentina, Brazil, and China and the imposition of countervailing duties on imports from Brazil. Preliminary investigations determined that the petition warranted a full investigation of the allegations.

The Clean Air Act of 1990 was passed by the Congress and signed by the President in November 1990. Provisions of the new law require a 35% reduction in hydrocarbons and a 60% cut in nitrogen oxides beginning in 1994. In addition, catalytic converters must be guaranteed by manufacturers to last double the current 50,000 mi. As a result of these changes, increased amounts of platinum-group metals (PGM) are expected to be used in each catalytic converter.

EXPLORATION

International Overview

After the days of increased base metal prices and frantic gold exploration of the late 1980's, mineral exploration in 1990 continued at a reduced level. The lower gold price forced a reassessment of the viability of smaller and more remote discoveries. Many junior exploration companies were forced to make radical writeoffs of exploration expenditure on these prospects.[9]

Exploration for nonfuel minerals continued to decline after 1988 as recessionary pressures slowed growth in the industrialized economies. However, 1990 expenditures were still significantly greater than the low levels experienced in the mid-1980's. The Persian Gulf crisis introduced increased instability in energy prices and more uncertainty to the global economic picture.

Exploration funding levels are generally determined by cash-flows. Therefore, commodity price and production levels affect funds available for exploration. Average gold prices for 1990 were slightly below the 1989 levels and significantly below 1987 levels. However, gold remained the major focus of mineral exploration in 1990. In addition to the lower gold prices, three factors had a large impact on worldwide exploration: the ending of flow-through funding in Canada, the introduction of the Australian gold tax, and the squeezing of margins on the deep South African gold mines. Estimates by the Prospectors and Developers Association of Canada suggest that spending will be about Can$610 million for 1990, with a projected 30% cut in 1991.[10]

Base metal exploration was not encouraged by the recession in North America and Europe and the uncertainty surrounding events in the Gulf at yearend. Exploration of platinum-group elements continued at a reduced rate compared to that of 1989.[11]

Although many Western economies were in various stages of recession, copper, steel, and zinc prices remained steady or declined only slightly. Prices were nowhere near the low levels experienced in the early 1980's, and production in domestic and world markets was above 1989 levels.

One note of hope was the opening of Eastern Europe and, less certainly, the U.S.S.R., to commercial exploration. Although a considerable amount of discussion occurred on the formation of joint ventures with state companies, few contracts were signed.[12]

Domestic Overview

The U.S. Bureau of Land Management's (BLM) claimstaking data reflect a subtle shift to base metals in the United States. Arizona was the only State with a significant increase in new claims on Federal land. New claims in nearly all other States declined precipitously. The number of new claims follows the gold price very closely. Data for 1990 show claimstaking at about one-half of 1988 levels.

Data on domestic exploration expenditures by U.S. firms were collected in the Society of Economic Geologists (SEG) annual survey. It showed that a substantial decline in exploration occurred in 1989. For 1989, the inventory of claims serviced by BLM did not change significantly. However, in fiscal year 1990, there were about 50,000 more claims released than new claims accepted by BLM. The SEG survey also shows that about 30 cents of every exploration dollar spent by U.S. firms went outside the United States.[13]

Antarctic Exploration.—Antarctica is the last continent unspoiled by man, and environmental proponents want to keep it that way. However, mineral industry executives and some governmental officials believe that Antarctica is too potentially rich in minerals to be completely conserved. Although an exploration prohibition is not in place, no Antarctic exploration has been conducted owing to the uncertain legal status of owning and developing a deposit, which is expected to be costly, considering accessibility, environmental concerns, and weather conditions.

An agreement regulating exploration, the Convention on the Regulation of Antarctic Mineral Resource Activities (CRAMRA), was adopted in 1987, but it still needs three votes to come into force. The United States is among the nations that have not signed the pact. The 101st Congress passed two bills that opposed ratification. The Administration has not yet decided whether it will sign the bills, but is thought to be leaning away from any measure that would impose a "permanent" ban on exploration. Some members of Congress believe a "permanent" ban would restrict any exploration for at least 100 years. Administration officials, including the head of the U.S. delegation, are thought to be in favor of a 30-year moratorium. Administration and industry representatives believe it will take at least this long for the Antarctic mining technology to be developed and made cost-efficient.[14]

The American Mining Congress (AMC) told a House subcommittee that a legal regime for mineral exploration in Antarctica should be in place before companies can be expected to invest in the region. The AMC criticized the CRAMRA because "explorers for hard minerals would face too much uncertainty and too much red tape under its terms." A spokesman stated the national agreement would provide "absolutely no incentive" for mining concerns that may be interested in mineral exploration in the future.[15]

Because of constraints on mineral development in Antarctica, minerals with the best prospects of recovery would have to be low-volume, high-value minerals such as gold. Even if a major oil deposit were found in the near future, oil recovery in the region is unlikely before the year 2020, according to the study. It is also unlikely that anything smaller than a giant (500 million to 5 billion bbl) or supergiant (more than 5 billion bbl) field would ever be economical to develop.[16]

Alaska.—Exploration expenditures rose 19%, from $47.8 million in 1989 to $56.7 million in 1990. Almost one-half of that, $24.9 million, was spent on the three gold properties in advanced exploration near Juneau—the Kensington (Echo Bay-Coeur d'Alene Mines), the AJ-Treadwell (Echo Bay), and the Jualin (Placer Dome-Granges). Another $11 million was invested in the Fairbanks area. This was predominantly spent on drilling the Ester Dome by Citigold and American Copper and Nickel Co., and on the Fort Knox property by Fairbanks Gold Inc. There was also significant exploration activity on the Seward Peninsula at Rock Creek, Anvil Creek, and Mount Distin by a complex joint venture that included Tenneco Minerals, Aspen Exploration, and the Sitnasuak and Bering Straits Native Corps. Moneta Porcupine Mines drilled three holes in the Lik deposit in 1990 and agreed to buy GCO Minerals' 50% stake in the project. The other 50% is owned by Echo Bay Mines. Stated reserves at Lik, which is only 12 mi from Cominco's Red Dog Mine, are 18 million st grading 10% zinc, 3% lead, and 1.5 oz per st silver. Initial plans consider milling 12 million st/yr, but an additional 10,000 to 15,000 feet (ft) of drilling will probably be necessary to refine the reserve picture.[17]

Drilling Technology. — **Arctic Gold Placer Drilling.**—Exploration drilling and the mining of marine placer gold deposits was initiated in the Arctic off Alaska. Prospecting and ore reserve drilling was done both in the winter on the pack ice and in summer from a modified Landing Craft Tank (LCT). Weather was a major controlling factor, and both drilling seasons lasted approximately 4 months each, on the ice from December to April and at sea from July to October.

Western Gold Exploration and Mining adapted a Becker[18] diesel top hammer drill to operate on a special broad-based skid in winter. This spreads the 41-st rig load over an 883-square foot (ft^2) area; the rig can safely work on ice only 2.5 ft thick. This modified rig can be lifted by crane onto the drill ship in about 4 hours. The drill pipe used is dual-walled, 5.5 inches (in) outside diameter (OD) and 3.3 in inside diameter (ID) and, in sea depths up to 115 ft deep, can penetrate to 164 ft below the seabed. With a high-pressure booster compression, holes down to 230 ft have been achieved.

After bit-design trials, the most satisfactory is an eight-track bit with a crowd-out profile. This pushes excess sediment away from the central bore and reduces the frequency of blocking. Bits with a crowd-in profile are satisfactory in the more granular sediments, but tend to push too much sediment into the inner barrel and cause frequent blockages.

The drill ship uses a four anchor system laid out at 45°, providing possible coverage of 62 acres. In theory, 16 holes can be drilled from one anchorage when drilling on 330-ft centers. Moving the anchors is accomplished by controlled winching and takes less than 10 minutes (min) to move from one hole to the next. During 4 seasonal programs over the past 2 years, an average of 10 holes per day were drilled. The Becker drill can also operate in a purely rotary mode to produce cores for detailed geological evaluation.

Reverse circulation (RC) drilling in conjunction with down-the-hole hammers (DTH) combines the advantage of DTH penetration speed with rotary chip-sample efficiency. Several companies are marketing RC-DTH hammers and dual-wall rods.[19]

Reverse-Circulation Drills.—In the Entec Sampler system, high-pressure air is split so that one flow operates the 2,000 blows/min hollow piston as the second airflow bypasses the piston and is jetted upward behind the bit face. This causes a powerful suction that collects all the cuttings from the bit face and passes them directly up through the hollow piston and into the dual-wall drill pipe. Some other RC systems pass the cuttings up the outside of the hammer before they are guided via a special crossover sub into the inner drill tube. This can result in significant mineral losses due to smearing against the borehole walls.

Entec Industries reports that, in tests on a gold mining operation in the Western United States, their Samplex hammer gave more than 98% by volume cutting recovery and that just more than 15% of the sample was 0.5 in or larger. This enables the geologist to make a more detailed description of the rock types and helps produce more accurate borehole logs.

Bul Roc (United Kingdom) developed a similar type of RC-DTH hammer and reports that penetration rates of more than 39.4 feet per hour (ft/h) were fast enough to overcome ground water entry and produced dry bulk samples in a hard limestone in northeast England. The use of a 300-pounds-per-square-inch (psi) compression

in holes to 262 ft or less contributed to the restriction in water flow. Water flowed into the hole during rod changes, but if this water was blown clear before rock penetration was resumed, then dry bulk samples were obtained.

Halifax Tool Co. (Halco) introduced its new RC-DTH hammer, which has a stainless steel central sample tube to reduce corrosion problems. This tube can be replaced without dismantling the entire hammer, which is often a major problem on the drill site. Halco gives great importance to the ease of maintaining and servicing its hammer on-site. The Halco dual-wall drill pipe is unique in that it is in integral lengths, has no separate central couplings, and uses no "O" rings. Halco claims that both inner and outer tubes transmit torque.

Core Drill (United Kingdom) Ltd. of Warwick has produced a double-tube swivel core-barrel and bit that cuts a 11.8-in-diameter core by 14.4 in (OD). During field testing, the strata were sufficiently soft to use a special TC core bit, and the double core springs effectively retained the marl and siltstone cores. One of the few problems was in handling the full 3.3- to 16.4-ft core-barrel and in safely transporting cores that weigh 122 pounds per foot (lb/ft).[20]

Drill Systems Premiers EXPLORER 1000 Drill.—The EXPLORER 1000 is designed to operate in environmentally sensitive areas. The drill is mounted on a proven carrier manufactured by Canadian Foremost of Calgary, Alberta. The carrier is four-wheel drive and operates on terra tires, giving the unit a ground pressure of 10.2 psi. This all-terrain vehicle is also equipped with articulating and oscillating frame features that permit drilling in severe off-road conditions with minimal ground surface disturbance. The drill is specially designed for dual-wall reverse circulation drilling for the mineral exploration industry and is equipped with a deck raise that allows the deck of the drill to be leveled on mountain and/or hill sides with the carrier's wheels on the ground surface. Other standard features include a bulldozer blade, sliding angle mast and deck slide, 750 cubic feet per minute (ft^3/min) at 350 psi air compressor, 485 horse power (hp) diesel deck engine, and a top-head rotary head that pivots to horizontal position providing an efficient pipe-handling system. The unit is completely self-sufficient and is capable of carrying a large supply of drill pipe. Under suitable conditions, the drill has a rated depth capacity of 1,000 ft using Drill Systems' 3 3/4-in dual-wall drill pipe.[21]

Rotary Drill Rig.—Ingersoll-Rand (IR) Co.'s rotary-drill division introduced a hydraulic tophead-drive drill rig designed primarily for mineral exploration. This drill uses either a rotary or downhole hammer with conventional or dual-wall drilling methods. The truck-mounted, deck-engine-powered TH75E features a "dump-angle derrick" system designed for angled exploration drilling. This system can position the derrick at any angle between vertical and 45°, then automatically move the derrick structure downward until the base rests firmly on the ground. Once the desired angle is set, an automatic pinning feature secures the deck in place. To make operations easier and more efficient at all angles and to ensure that the operator is always near the hole, the TH75E's control panel is positioned on the derrick and adjusts to a comfortable angle for the operator. The drill-pipe handling systems allow rapid, safe pipe changes in the vertical or angle positions. The TH75E is capable of handling 4 1/2-in by 20-ft dual-wall pipe and can be supplied with a complete dual-wall package. The TH75E also has some unique features that include a two-speed rotary head design (that can be shifted "on the fly"), a remote control clutch between the engine and air compressor, and a remotely retracting hydraulic-powered top-head drive.[22]

All-Hydraulic Core Drill. — The Diamec-232, from Diamond Boart Craelius Inc., is an all-hydraulic core drill with mechanized rod handling. All-hydraulic means one person can perform all drilling and handling operations from the control panel. No tools are required with its mechanized rod handling feature. The machine is especially suitable for coring and drilling grout holes in narrow drifts or galleries. With its light weight and compact size, the Diamec-232 is easy to set up for drilling. This drill offers an advantage of fast moves between sites, without disturbing normal production routines.[23]

Landing Indicator.—Manufactured by Longyear Canada Inc., the landing indicator is a device designed to improve productivity in diamond core-drilling operations. It is a fluid-pressure-activated device that tells the drill operator the inner tube assembly has landed in the core barrel and drilling may be resumed. This avoids unnecessary delays estimating the time required for this operation. The landing indicator also reduces the chance of drilling in a mislatched condition. It is available for several core barrel types, including BQ, NQ, HQ, CHD 76, and CHD 101. The indicator is built into the inner tube assembly of the wireline system of core barrels. The landing indication occurs as an instantaneous fluctuation on the fluid pump gauge. This fluctuation is a result of increased pressure required to push a steel ball through a nylon bushing in the latch body. When the inner tube assembly contacts the landing ring, the waterflow is diverted through the latch body, applying pressure to the ball. Momentary pressure increase of approximately 300 psi forces the ball through the nylon bushing.[24]

Marlow Man-Portable Drill. — The Marlow Mole DD2 man-portable multipurpose drill equipped with a remote portable hydraulic power pack was field-proven from the Arctic to the tropics without modification. Conceived as a state-of-the-art drill suitable for diamond core drilling, auger, DTH hammer, and slim hole RC drilling, a conservative depth rating of 165 ft was claimed by the manufacturer. However, it has now been shown that a 330-ft depth can be achieved using a thin kerf, double tube 1.8-in-diam core barrel taking a 10-ft core on each run and drilling at an angle of 60°. As the Mole DD2 has an integral dual-purpose gearbox (0 to 150 revolutions per minute (r/min) and 0 to 1,250 r/min), it is possible to auger rapidly through overburden and case or to simultaneously drill and case through to bedrock, then withdraw the interior drill string, leaving the casing in bedrock prior to continuing the hole by diamond drilling.[25]

***Ground Surveying.*—GPS Receiver.**—The GPS Nav 1000 Pro is one of the least expensive handheld global positioning system of satellites (GPS) receivers currently available. Cost savings are experienced through the Nav 1000 Pro's ability to replace a surveying team in determining preliminary calculations and positions. The uses of the Nav 1000 Pro include establishing survey control in remote, unmarked areas in the field, plotting coordinates, and storing coordinates. The Nav 1000 Pro is capable of storing up to 200 position fixes in its data buffer. These fixes may then be downloaded through its RS232

port into a data logger or laptop computer. The unit weighs only 30 oz and is shock resistant and waterproof.

Portable X-Ray Analyzer.—The metal Analyzer Probe (MAP) III Portable X-Ray Fluorescence Analyzer, from Scitec, allows the prospector-explorationist to have on-site, real-time analysis performed for assessment work. No sample preparation is required, and each analysis takes an average of 1 minute. MAP III is a hand-held, multielement probe that performs quantitative analysis for silver, base metals, and trace elements, including those elements associated with gold. The in situ analysis can be performed in drill holes up to 250 ft deep.[26]

Laser Mapping.—A new method to map planar geologic features in underground mines—where metal interferes with compass readings—is being patented by the U.S. Bureau of Mines. Based upon extensive testing, time savings of 50% in mapping—using the "geolaser"—are estimated. The geolaser operates on the principle that any beam of light laid horizontally along a planar feature will define its strike. Thus, the laser can project where a planar feature should occur along the back or opposite rib in an underground drift.

Geophysical Surveying.—The development of new geophysical and geochemical techniques and equipment continued during 1990 at a somewhat decreased pace from former years, in part reflecting generally reduced levels of mineral exploration in most parts of the world. There were, however, some notable highlights. Several new sensitive magnetometers for aeromagnetic survey work are in an advanced stage of development in North America. The first triaxial aeromagnetic gradiometer system was built in the Republic of South Africa. In Australia, considerable funding is going into the development of airborne electromagnetic survey systems. The Global Positioning System (GPS) is now being employed by most airborne survey operations and making feasible preliminary field compilation of survey results.[27]

Remote Sensing.—Development of Landsat 6, the next-generation U.S. land remote sensing satellite, is on schedule for launch in late 1991, according to the Earth Observation Satellite Co. (EOSAT). Landsat 6 will orbit the Earth at the same altitude, inclination, and with the same equatorial crossing time as Landsats 4 and 5, both of which are still operational. The Landsat 6 enhanced thematic mapper will provide improved spatial resolution capable of discerning objects smaller than a tennis court. The satellite will have the same multispectral imaging capabilities of Landsats 4 and 5—technology still unrivaled by any other commercial remote sensing platform.[28]

Projects.—Agnico-Eagle Mines Ltd., Asamera Minerals Inc., Comaplex Minerals Corp., Hecla Mining Co., and Lucky Eagle Mines Ltd. jointly announced the results from drilling for gold mineralization on the Meadowbank Project, about 60 mi northwest of Baker Lake in the Northwest Territories, Canada. In 1989, the third year of exploration drilling the Third Portage property, 12 diamond drill holes defined mineralization to a 300-ft depth over a 1,300-ft strike length. A followup program to test the continuity and size of the deposit is budgeted at Can$1.15 million and was scheduled to begin by mid-1990.

In Mexico, Campbell Resources Inc. has gold properties covering 400,000 acres in the State of Sonora. Most notable is the reserve at La Colorado with a reverse-circulation drill program planned for 1990 and a feasibility study for 1991. Also in Mexico, more than 5 million st of gold ore in massive sulfide mineralization has been outlined on the Cerro de Oro property, including a zone containing 0.07 oz/st gold and 1.9 oz/st silver.

Anglo Swiss Mining Corp., formerly Carolin Mines Ltd., recently announced plans for a $1 million exploration of its 1,500-short-ton-per-day (st/d) Ladner Creek gold mine near Hope, British Columbia, Canada. The exploration will be followed by a feasibility study conducted by Wright Engineers Ltd. An independent consultant estimated potential geological reserves of 5 to 6 million st in addition to the 990,000 st of defined gold mineralization, with expected grade on the McMaster zone.[29]

Stroud Resources Ltd. reported that diamond drilling increased reserves of the Creek zone on its Hislop property, near Timmins, Ontario, Candad, to 1.016 million st grading 0.186 oz/st gold. The Main zone, about 1,600 ft southeast along the strike, contains an estimated 102,000 st grading 0.17 oz/st.[30]

High Frontier Resources Ltd. acquired the Washington Dome Project in Washington County, UT. The property consists of approximately 2,880 acres of unpatented placer and lode claims, as well as a royalty interest in an additional 480 acres of unpatented placer and lode claims (about 133 claims). The property is on the axis of the Virgin anticline in Permian and Triassic rock.

Placer Dome (U.S.), Inc., recently completed the second phase of its exploration at Mexican Hat, AZ, spending $1.39 million to date to earn a 60% interest in the property. About 137 holes have been completed, including 54,103 ft of reverse circulation and 8,017 ft of core drilling on the relatively shallow volcanic-hosted target. Fire assays were made on drill holes that were completed in 1990.

Coral Gold Corp., with Amax Gold Inc. as the operator, reported the first drill results from a four-phase, $11.5 million exploration and development program for the Robertson gold property on the Battle Mountain gold trend of northern Nevada. The first deep hole produced gold values from near surface to a depth of about 1,900 ft.[31]

Windarra Minerals Ltd.'s subsidiary, Westward Explorations Ltd., together with its partner and operator, Cameco, and Uranerz Exploration and Mining Ltd. claimed a major new discovery after drilling over the lake section of the Bakos zone of the Preview Lake property in the La Ronge area of Saskatchewan, Canada. Previously reported reserves in the BK1 and BK2 zones are 1.2 million st probable at 0.29 oz/st gold plus 230,000 st possible at 0.31 oz/st gold.[32]

In British Columbia, Canada, attention was directed to the Golden Triangle that connects three new producing precious-metal mines (Golden Bear, Premier, and Skyline) and two advanced exploration areas encompassing about 175,000 square miles (mi^2) near its eastern corner. The three producers struggled to keep their portals open for the same reason five new gold mines opened and closed elsewhere in 1988-89. Golden Bear, Premier, and Skyline all have well-established reserves. However, production costs have far exceeded estimates due to the inaccessibility of the mines and infrastructure problems.[33]

Ghanaian-Australian Goldfields, Ltd. (GAG) finalized a second drilling program within its Iduapriem gold mining lease near Tarkwa in Ghana. The company drilled 48,000 ft of diamond drilling in 178 holes. A resource of almost 17.6 million st containing an average of 0.06 oz/st gold was

delineated, contained within 3.1 mi of sedimentary rocks having a total strike length of 5.6 mi in the mining lease area. The resource includes 2.3 million st of ore averaging 0.08 oz/st gold. The company also located low-grade mineralization in other areas of the property. The sedimentary host rocks were also found in GAG's adjoining prospecting license areas.

Boulder Gold's U.S. subsidiary, Chrome Corp. of America (CCA), reached an agreement with Phelps Dodge Mining Co. on its Stillwater Complex. The property includes two previously operated chromite mines, one of which, the Mountain View Mine, would be reopened for the project.

Ontario's Ministry of Northern Development and Mines announced funding a 4-year Can$2.2 million Geological Reassessment Program for the Elliot Lake region. The project will concentrate on the potential for deposits of base metals, PGM's, and aggregate resources and industrial minerals. Separately, the Ministry will provide Can$50,000 to support the evaluation of prospecting technology developed in the U.S.S.R. A group of researchers led by the Ontario-based geophysical firm Scintrex Ltd. will test a geoelectro-chemical method for prospecting that was developed in the U.S.S.R. over the past 30 years. The method can reportedly detect the presence of ore formation elements at considerable depth, making it potentially valuable for exploration in areas covered with deep overburden. The work will be carried out by Soviet scientists in collaboration with industry, university, and government.[34]

Recent geologic studies in northern Minnesota indicate a greater potential for deposits of gold and silver in the area than had previously been thought, a U.S. Geological Survey scientist told a meeting of mining engineers and geologists in Salt Lake City, UT. "Geologists' mapping and geochemical surveys in northern Minnesota have revealed mineralized shear-zones and bedrock fractures similar to those in known gold- and silver-producing districts, including nearby areas in Canada."[35]

Pegasus Gold Corp. announced two joint ventures: one with Lac Minerals Ltd. in New Mexico and another with Quartz Mountain Gold Corp. in southern Oregon. Spokane, WA-based Pegasus and Toronto-based Lac Minerals will explore and develop the Ortiz gold project in a mining district 25 mi northeast of Albuquerque, NM. Pegasus will be the operator. Several deposits are on the property, but the joint venture will address the Lukas Canyon deposit, which could be in production in less than 2 years. The total geologic resources are estimated to contain 1.4 million (troy) oz of gold.[36]

Homestake Mining Co. announced a 5-year, $23 million underground exploration program to follow up encouraging gold discoveries approximately 3 mi north of its Homestake gold mine near Lead, SD. Deep drilling from the surface intersected the gold mineralization more than 1 mi below the surface. The exploration program will include a drift from existing Homestake underground operations to reach the mineralization.[37]

Inco Ltd., Vior Inc., and Cambior Inc. announced a new gold discovery on the Douay j.v. property 8 mi northeast of Joutel, Quebec, Canada. The j.v. property, which covers approximately 18 mi^2, is owned by Inco Ltd., the operator; Vior; and Cambior. An ongoing diamond drill program intersected 60 ft containing 0.23 oz/st gold and included 16 ft grading 0.35 oz/st and 10 ft grading 0.39 oz/st gold.

Canyon Resources Corp. announced that more than 600,000 oz of gold was discovered at the Briggs deposit in the Panamint Range, CA. In its recent purchase of Addwest Gold, Inc., Canyon acquired 100% ownership of the Briggs property, which includes approximately 24,000 acres of mining leases and claims in the southern Panamint Range.[38]

DEVELOPMENT

A small decline occurred in the total number and value of new mining- and mineral-processing projects worldwide: 318 at a projected capital cost of $59,700 million in 1989 versus 296 at a projected capital cost of $55,700 million in 1990. The data may indicate a trend toward greater stability, with robust markets returning for certain base metals. Projected investment in North American copper production at $1,260 million almost doubled the figure of the previous year. In Asia, projected investments soared to $1,680 million, nearly triple the total of the previous year. Worldwide productive capacity for copper was predicted to increase by as much as 775,000 st between 1990 and 1992.[39]

Alaskan Mines

According to the Department of Natural Resources, lower development spending but a higher level of mineral revenues is attributed to the changing status of two big mineral projects, Greens Creek and Red Dog, from development to production. The final development cost of $144 million for Greens Creek is substantially higher than the $80 million estimated 3 years ago. An environmental benefit at Greens Creek is the relatively small area that will be required for tailings disposal. Approximately 50% of the tailings will be used as backfill underground, and the employment of a mill process that yields dry tailings has reduced the size of the surface tailings disposal area to 34.6 acres—less than one-third that which would be required for a wet-tailings area for a mine of an equivalent size.

Regulatory officials accused Red Dog of fouling the fish-rich Wulik River with zinc and cadmium downstream from the mine. The company must pump contaminated water back upstream into the company's tailings pond, build culverts to divert uncontaminated water into the streams, and submit plans to prevent future ground water seepages. When in full production, the Red Dog open pit is expected to produce 560,000 st/yr of zinc concentrates, 120,000 st/yr of lead concentrate, and 50,000 st/yr of bulk concentrate from 2.1 million st/yr of mined ore.[40]

The National Park Service (NPS) completed an environmental impact study on mining activity in three national parks in Alaska: Denali, Wrangell-St. Elias, and Yukon-Charley Rivers. The study was done in response to a lawsuit brought by several environmental groups. The review evaluated the effects of mining, including cumulative effects, within the three parks. The study recommends that NPS reacquire all lands held under both mining patent and claims in the three parks. NPS will make a final decision after a procedural review of the study and determination by the EPA.[41]

Mining Manganese From the Ocean Floor

In November 1990, the U.S. Department of the Interior and the University of Hawaii's Look Laboratory released the long-awaited final Environmental Impact Statement (EIS) on mining manganese nodules from the ocean floor near Hawaii. The study is the culmination of a 6-year effort by a State-Federal task force. The two-volume report points to the possibility of a new source of cobalt, manganese, and platinum ore for American industry, as

well as new economic opportunities for the State of Hawaii. Ocean floor mining would do little harm to marine life because there is little life under 8,000 ft of water, according to the report. However, bigger environmental problems would occur on land where the nodules would be processed, including air pollution, ground water contamination, noise, landfilling, and the need for large areas of land. The nearest leasable tract is about 200 mi from the main Hawaiian Islands.

Hawaii's Look Laboratory scientists said it is unlikely such a plant would be built in Hawaii because of strict Federal environmental controls. It is estimated that it could take another 10 years to develop the technology to mine the ore. The EIS addresses 10 potential seamount mining sites, estimated to contain 2.9 million st of cobalt, 1.8 million st of nickel, and 89 million st of manganese. Commercial amounts of platinum might be present, but that has yet to be confirmed.

New Nickel Projects

Strong nickel prices during 1988 and the first half of 1989 brought several previously shutdown mines back to life in 1990 and have prompted a spate of investment in new mines. Three underground mines are in the preproduction stage in the Sudbury basin and at least three more, in Botswana, Western Australia, and Indonesia, are at comparable stages of development. Another eight nickel projects are under consideration for development.

The largest of the projects at the feasibility stage is BRGM's proposed $1.03 billion Tiebaghi development in New Caledonia. The project, in the north of the islands, would include a refinery that would incorporate BRGM's hydrometallurgical process.

In Western Australia, the Mount Keith deposit is under consideration for development by a joint venture of Australian Consolidated Minerals (50%) and Outokumpu Mining Oy (50%). Preliminary estimates for development cost are on the order of $330 million. Reserves, which would be mined from an open pit, total 270 million st, grading 0.6% nickel.[42]

Cyprus Reopens Iron Ore Property as Northshore Mining

The taconite mine and plant at Babbitt and Silver Bay, MN, formerly called Reserve Mining Co., was brought back into operation. Cyprus Minerals Co. breathed new life in the property, which was in bankruptcy since 1986. Cyprus planned to produce more than 2.0 million long-ton (lt) pellets in 1990. By 1993, it plans to be producing 4.0 million lt/yr. Cyprus bought the bankrupt mine for $52 million in June 1989 and began a $29.9 million refurbishing program that will continue into 1991. The facility is undergoing renovations aimed primarily at meeting the requirements of its acid-pellet customers by increasing quality control and lowering costs. Northshore had only scheduled production of 1.7 million lt pellets in 1990, but interest from other customers raised that target to about 2.2 million lt in its first year of production.[43]

UNDERGROUND MINING

The Kiruna iron mine in Sweden is using innovative mining technology to increase production. Kiruna installed remotely controlled driverless trains for ore transport on the 775 level in the 1970's. This was a technically sophisticated system that still maintains a high efficiency. With its experience of the driverless trains, Kiruna is now developing a remote control system for LHD's, the so-called SALT Project (System for Automatic Loading and Transport). Filling of the loader bucket is remotely controlled by means of a television monitor and radio control. The rest of the LHD's working cycle is automatic, with the LHD following a cable in the floor of the drift. Using this system, for which production tests started in February 1990, one operator can control up to three LHD machines from a remote control room.[44] This parallels work being done by the U.S. Bureau of Mines on remote control LHD's for narrow underground veins. To more fully use the application of the remote control and automatic system, Kiruna is instituting a large-scale mining method by increasing substantially the distances between sublevels in its caving operations and arranging these sublevel stopes in blocks of nine. The block will be three stopes wide and three stopes deep, and the stopes are mined in sequence. Blast holes are drilled up 79 ft and down 427 ft from the sublevels. This is reportedly twice the distance that any other operation is drilling. The size of the stopes and concentration of operations should not only be more productive, but adaptable to automation.

Computerized 35-st trolley locomotives operating at Molycorp's New Mexico mine increased underground block caving production from 1,250 to 1,900 st/d. Computerized communications, command, control, and monitoring equipment are reportedly producing savings on the order of $500,000 per day.

The use of electric trolley trucks for underground applications continues with the purchase of a Kiruna-type truck and trolley system for haulage at Mount Isa Mines in Queensland, Australia. Wagner also introduced a new four-wheeled electric drive trolley truck for the industry.

A prototype compact underground boring machine for rapid excavation of underground exploration headings was developed by a joint venture and was tested in Canada. It is reported to bore 8-ft-diameter tunnels through hard rock at twice the rate of conventional drill-and-blast methods, with the inherent safety and improved working conditions of boring machines.

Hydrotransformers that drive closed-circuit, water-emulsion systems to operate equipment in the deep mines are now commercially available. The units were first shown to be economically feasible by the Kloop gold mine in the Republic of South Africa. The system operates rock drills, cleaning rods, watering-down and water-jetting guns, prop-setting intensifiers, and scraper winches for rock handling. Currently, one stope at the mine is operated completely by hydropower. Plans are to operate 40% of the mine with hydraulic systems.

An accurate nondestructive evaluation system to locate cracks in mine winder shafts and power-generating turbines is now being used in the South African mining industry. Originally developed to test turbines in nuclear power stations, the new hydropower system, containing 18 ultrasonic transducers mounted in 6 arrays, covers critical areas far more efficiently. Previous techniques used a single transducer placed at one end of a shaft. There are about 900 mine winder shafts in the Republic of South Africa.

Other innovations are the use of a grouting system and timber cribs for underground supports. The system consists of a pump, bag, and a high-yield grout with rapid setting and curing properties. The grout is chemically engineered to have the same comprehensive strength as the timber. It replaces blocking and wedging, a time- and labor-intensive process, and provides a more effective support.

To minimize wear and maintenance on vehicles used in trackless mines, one company developed a system of concrete paving slabs that interlock with a degree of flexibility to counter the less-than-perfect base found in underground mine haulageways. It can be installed with minimal disruption to the mining operation and is reported to result in cost savings for vehicle maintenance and repair.[45]

Drill-Split

Drill-split primary fragmentation, an innovative mechanical excavation method, was developed to supplement or supplant drill-blast methods. The hydraulically powered, radial-axial splitter used by the system breaks rock in a unique action that gives the appearance of pulling a plug of rock from the mass. This fragmentation activity causes the rock to fail in tension, resulting in highly efficient excavation. Because the radial-axial splitter reacts to the forces it generates internally, it is a small device that can be adaptively mounted on lightweight carriers to meet different excavation needs.

After extensive laboratory testing of smaller tools, the U.S. Bureau of Mines developed and built a field-scale drill-split machine that has the ability to excavate one-half st of hard rock per operation. Both the drill and splitter are mounted on an indexing mechanism that provides the handling and feed operations for both tools from a single highly maneuverable boom. The boom is carried on an air-track crawler chassis for complete mobility. Excavation by this system is carried out through repetitions of the basic drill-split process.

Field tests of the mobile drill-split fragmentation system were conducted in an underground limestone mine. During this test, the drill-split fragmentation system produced more than 100 st of ore and produced an average 1 1/4 st per break. The underground field testing demonstrated several desirable characteristics of drill-split fragmentation: (1) compatibility with concurrent operations, as the testing was conducted during the mine's normal day shift with no disruptions, (2) environmentally attractive operations that produce virtually no dust and no dangerous by-products, and (3) inherently safe operations because of the static, nonviolent excavation action. Drill-split is a low-cost primary excavation method with the flexibility to meet the needs of diverse operations.

Decoupling

Decoupling methods once used primarily at surface mines are finding increased underground applications. A good example is the Bureau's tests conducted in the Homestake Mine's Vertical Crater Retreat (VCR) stopes. Hanging wall blastholes were loaded with less than one-half the normal explosive and decoupled. In comparison to control panels using conventional blast designs, ore dilutions as great as 35% were reduced to 3% to 9%.

Concave Bit

The U.S. Bureau of Mines developed a new bit that promises greater productivity and longer life than conventional point-attack bits while using less force and energy. This new bit is called the concave bit because of its concave front surface. Normally the efficiency is better when the concavity is greater. It has a round shank that allows use with standard bit holders and continuous rotation making the entire periphery of the front surface the effect cutting edge. This bit is designed to replace drag bits and can be used on all mechanical excavators such as roadheaders, continuous miners, shearers, and plows.

Camera System on Roadheader

Closed-circuit television equipment specially designed for use in mine development work by Rees Instruments Ltd., United Kingdom, is reported to have successfully completed trials at British Coal's Sherwood Colliery in Nottinghamshire. The system, incorporating an R331.01.000 intrinsically safe camera and R305.00.000 flameproof monitor with integral IS power-supply unit was developed by Rees in order to improve roadheader performance and enhance the operator's safety.

In roadway drivage underground, once the roadheader's boom-mounted cutting head has made sufficient progress, the machine is withdrawn to allow insertion of steel support arches, before advancing again. When it does, the machine must cut out past the last arch set on the blind (left) side. This is normally a two-person job, with one acting as a "spotter" to pass information to the operator.

The camera-television system dispenses with the spotter. The camera is mounted in a stainless steel tube inside an adjustable steel box on the handrail at the left side of the roadheader and transmits black-and-white pictures to a 12-in screen within its flameproof enclosure. The driver can thus accurately position the machine prior to resuming cutting.

Rees engineers found that, in practice, certain on-site modifications were necessary because of the tough mine operating environment, but excellent pictures are now being achieved consistently, and the system is used by all drivers. Modifications have included mounting a diffused headlight on top of the camera enclosure to improve lighting levels. Once actual cutting has started, the television picture is obscured by the reflection of the main lights on the machine on the dust but, by this time, the camera has fulfilled its purpose and accurately positioned the cutting head.[46]

SURFACE MINING

The advent of the microprocessor and its adaptation to the rugged conditions of mobile-equipment operations in the mining industry has caused a radical, but often underestimated, revolution in surface mining. The range of this new technology is all-embracing. It includes geological and survey instrumentation, geotechnical measuring devices, manufacturing design of all types of mobile equipment, and applications in control, operation, and maintenance of all types of surface plants. The variety of microprocessor uses include monitoring drilling performance parameters, providing fault system diagnostics for electric face shovels, measuring ore weights in loaders and trucks, and eliminating torque spikes in large mechanical-drive trucks. The pace of change has been and is rapid. New fields continue to open, and it is not unlikely that the next decade will see such items as the guided automatic haul truck or the automated rock drill.[47]

The number of surface mine closures in 1990 due to depressed markets was small and largely offset by the number of mines opened. Gold remained the most sought-after commodity. Copper continued to stage a remarkable recovery. High commodity prices continued to fuel the strong comeback. Asarco announced plans to spend an additional $80 million at its Ray Mine and Silver Bell unit in Arizona. This will further expand the company's total domestic copper production from 220,000 st to 360,000 st/yr.

Santa Fe Pacific Gold began production at its $77 million Rabbit Creek Mine near

Winnemucca, NV. The 1,600-st/d carbon-in-leach (CIL) plant is expected to produce 100,000 oz/yr in 1993. The company also announced plans to expand the production capacity at the mine and mill to 200,000 oz/yr by 1992 at a cost of $60 million. The direct cost of production for the expanded plan is expected to be $190 per oz. Proven and probable gold reserves at Rabbit Creek is 3.6 million oz. American Barrick is in the midst of a major, $365 million expansion program at its Goldstrike Mine near Elko, NV. When completed, the mine will increase its production from 352,880 oz in 1990 to 900,000 oz by 1993. Pegasus Gold began building the $11.8 million Black Pine open-pit, heap-leach gold mine in Idaho. The mine is expected to produce 40,000 to 80,000 oz/yr.

Atlas plans to spend $80 million to develop the Grassy Mountain Mine in Oregon to produce 100,000 oz/yr of gold and 100,000 oz/yr of silver for 8 years.

The Denton-Rawhide is a joint venture among Kennecott, Kiewit Mining Group, and Plexus. The open-pit, heap-leach operation began operation in 1990. The mine is expected to produce 80,000 oz/yr of gold and 399,000 oz/yr silver for the next 5 years.

Battle Mountain was given the go-ahead to develop its San Luis Project in southern Colorado. Total cost of the carbon-in-pulp (CIP) facility is estimated at $20 million. At full capacity, the San Luis plant will produce 61,000 oz/yr. Cominco brought the Red Dog zinc-lead mine into production at a cost of $415 million. Current reserves at Red Dog are 85 million st at 17% zinc, 5% lead, and 2.4 oz/st silver.

The Escondido Mine came on-stream in northern Chile. This $900 million mine and concentrator is expected to produce 352,000 st/yr copper in concentrates. Geologic reserves amount to 2 million st grading 1.6% copper. Production began at the Bogosu gold project, a joint venture between Billiton BV (62%), Sikaman Gold Resources (14%), IFC (13.5%), and the Government of Ghana (10%). The $86 million open-pit mining operation has reserves of 21 million st grading 0.1 oz/st. Gold production at the (1.2 million st/yr) mine is expected to total 137,000 oz/yr.

The Porgera Mine Project consists of Placer Dome (30%), Highlands Gold (30%), Renison Goldfields (30%), and Papua New Guinea (10%). The $1 billion project is expected to produce 900,000 oz/yr of gold at an average cost of $150/oz. Ore reserves are 56 million st grading 0.22 oz/st gold. The Granny Smith mine (Placer Pacific 60% and Delta Gold NB 40%) began gold production at a rate of 150,000 oz/yr in Western Australia. The $77 million project contains ore reserves of 25 million st, with an average grade of 0.05 oz/st.[48]

Alcoa closed the last operating bauxite mines in the United States at the end of May 1990, after 91 years of operation because ore reserves were exhausted. The mines are in Saline County, AK, adjacent to Alcoa's Arkansas operations. The operations include a bauxite refinery and alumina chemical facilities. The refining operations, which produced 275,000 st/yr of alumina, will also be closed. Chemical production will continue at the site using alumina feedstocks from other Alcoa locations. For most of the history of the plant, alumina was produced to be made into aluminum, but more recently the alumina was used to produce 135 different products from 6 alumina-based chemicals. These chemical products were used in high-performance refractories and cements, ceramics, fire retardants, and in paper and pharmaceuticals. About 200 people either retired or were laid off, reducing staff at the plant to about 700.[49]

Equipment

Perhaps the two most obvious trends in the past few years have occurred in haul trucks. The 240-st-capacity haul trucks appear to be here to stay, as well as the mechanical-drive, 170-st trucks from Caterpillar. One major trend common to both mechanical-drive and electric-drive systems trucks is the rapidly improving electronic control systems. A memory logger can be placed on-board to record the readings of a wide assortment of gauges. When problems occur, they can be played back in the shop, revealing under what conditions the problem appeared, much like a flight recorder. If a failure occurs, the on-board electronics can not only determine which component has failed, but how serious the failure is, whether it requires immediate attention, or whether service can wait until the end of the shift or later in the week.

Haulpak (Komatsu-Dresser) is one of several manufacturers offering its own on-board weighing system. In the Haulpak system, sensors are mounted in strategic places in the frame of the truck and connected to a microprocessor in the payload meter mounted in the driver's cab. While the driver watches the weight, the shovel operator watches the light assembly mounted outside on the deck. The lights flash green, amber, and red, depending on whether the truck is underloaded, loaded between 90% and 105% of rated capacity, or overloaded. Because the system has a microprocessor, it is capable of recording the final weight just before the truck begins its haul. The payload meter has the capacity to store data for 200 haul cycles. A printer is available that typically lists the driver, total number of loads, the weight of each load, the time each haul cycle began, the date, and the total weight moved for that shift.

High quality is another trend. All manufacturers are gaining a solid reputation for reliable machines. Problems inherent with the larger haul trucks have largely been overcome. Haulpak has a multimillion dollar test center where entire truck frames, pulled off the assembly line at random, are tested with bending and twisting loads, simulating years of normal stress in just a few day's time. Any potential problems show up in the laboratory where they are corrected before they have a chance to cause downtime. The result is that their frames have benefited from increased reliability.

Many remarkable trends are found in front-end loaders (FEL's). In addition to their increasing size, they are also benefiting from the electronics revolution. Loaders are also beginning to compete with shovels in some applications. Not only are loaders more mobile than shovels, they can clean up more efficiently.

Many mines have introduced in-pit crushing with mobile crushers, and many more are considering it. Conveyors can move material inexpensively, but need an in-pit crusher to ensure the proper size material. For mobile crushers with mobile connecting belts, FEL's are required to move the material the short distance from the face to the crusher head.

Big loaders in easily diggable material offer shovels more competition. The FEL is more maneuverable than a shovel and requires a lower initial investment. It can be easily moved to get out of the way of blasts. The FEL can also do limited load-and-carry work.

This trend toward using FEL's as short-haul units is causing a change in their design. FEL's are required to haul material further as distances increase between the face and the crusher hopper. Suspensions of FEL's are notorious for having very little shock absorption, causing them to

bounce wildly at increased speeds. Now, Caterpillar has introduced a Ride Control System to allow FEL's to move material longer distances at higher speeds.

Caterpillar has come up with a clever way for a FEL to weigh the material in the bucket—not just while the machine is at rest, but while it is in motion. Knowing how much is in each bucket can greatly aid loading a truck to its proper capacity, not underloading or overloading. By taking the system dynamics and geometry of the loader and knowing where the various loads will be, the FEL's can precisely report the load in the bucket. The scales have an accuracy of 3% when the loader is moving and 1% when stationary. The hardware is the same as for Caterpillar's haul-truck payload monitors, but the software is different, taking into account the fact that the FEL will be moving while the load is being measured. It was under field tests in 1990 and was scheduled to be commercially available in 1991.

According to Caterpillar researchers, the next generation of electronic systems will monitor performance over the life of the machine, allowing performance trends to be easily spotted. This should happen soon because electronic memory is steadily becoming less expensive. Variabilities in performance can be traced to shifts, operators, or other variables. Also, a telemetry system would send operational data to a central point with more detailed software capable of spotting trends common to all trucks. Ultimately, these systems will provide a warning *before* a major failure, not just on an individual-truck basis, but on a fleetwide basis.

There is also a trend toward modular components. For example, in order to decrease downtime, many large units, especially haul trucks, have engines that can be changed out easily and their waiting replacements slipped back into place. The machine is immediately operational, with the shop free to repair or overhaul the engine without the intense pressure of getting the truck back out on the line again immediately.[50]

World's Largest Mechanical-Drive-Wheel Bulldozer.—A machine originally devised early in the past decade for use in the major opencast iron ore mines of Western Australia was further developed and refined for use in ore and coal mining and power station applications. The Tiger 690B, built by Tiger Engineering Proprietary of Perth, West Australia, is reportedly the world's largest mechanical-drive-wheel dozer with an operating weight of almost 90 st. It can be equipped with dozer blades up to 54 cubic yards (yd^3) capacity. Studies in Australia and North America reportedly show that the 690B can doze coal at 750 st/h over a one-way dozing distance of 600 ft. This increases to 1,000 st/h over 300 ft and 2,100 st/h at 100 ft.

A particular benefit of the machine design in bulk coal handling work is the high compaction effect of its large radial tires; this significantly reduces the risk of spontaneous combustion in coal stockpiles. Other tasks for which the machine is well suited are cleaning work around large mining shovels, push-loading scrapers, and selective dozing work in the large open pits.[51]

Largest Mineral-Sand Dredge.—The world's largest mineral-sand dredge, and the largest dredge of any kind in Australia, began work at Cooljarloo in Western Australia in December 1989. Eighty-seven mi north of Perth, Cooljarloo is the world's first integrated project to turn titanium minerals into paint pigment. Partners in the venture, which will generate annual exports worth Aus$200 million, are Minproc Chemicals Pty. Ltd., a subsidiary of Kerr-McGee. The "Cooljarloo I" bucketwheel dredge is the first electric line-shaft-driven dual-wheel excavator. The 900-hp dual-wheel excavator head is 160 inches in diameter and weighs approximately 110 st.[52]

Backhoe-Mounted Dredging Excavator. — Ellicott Machine Corp., Baltimore, MD, developed a hoe-mounted dredging excavator (HMDE) known as the "Hoe Dragon," which makes possible the continuous excavation and pumping of underwater minerals when used in conjunction with a standard model track-mounted backhoe. The combination of backhoe and dredging excavator is said to maximize the capability of the backhoe and provide continuous excavation and material transport from point of loading to disposal without interruption for swinging with boom and bucket manipulation typical of normal backhoe operation. It is in effect a new tool for underwater excavation of both loose and consolidated materials and can extract mineral in both a forward and aft digging mode.

The backhoe can also be walked onto a barge and operated as a swinging ladder-type dredge while discharging to a shore point, into another vessel, or attendant mineral processing system. This type of equipment is well-suited to recovery of small alluvial gold and diamond deposits inaccessible to floating equipment.

The Hoe Dragon offers the combined advantages of a dual-wheel excavator and a wide-bodied pump that transports virtually all excavated material. A flotation option is available in which special devices are fitted to reduce the submerged weight of the module. This feature allows its use in backhoes not normally able to handle the Hoe Dragon because of its weight. Flotation in this manner also allows for extended reach, without impairing the hydraulic or stability limits of the backhoe. Specially designed extendable stick mechanisms are offered for deep digging applications.[53]

Hydraulically Powered Machines Getting Bigger.—At surface mines hydraulic excavators are getting bigger—and are challenging rope shovels in more and more applications. Excavator weights have been climbing, and some of the newer hydraulic shovels on the market have working weights of 400,000 lb and more. One Supersize hydraulic excavator is Demag's H485, which has a gross operating weight of 1.2 million lb. The first units were placed in coal and tar-sand mines. A unit was put into operation in 1990 at Boliden Mineral's Aitik copper mine in northern Sweden. A 920,000-lb, 530- to 1,060-cubic feet (ft^3)-capacity prototype, the SMEC 4500, built by Japan's Kobelco, underwent long-term mine trials at BHP-Utah's Blackwater coal mine in Queensland, Australia.

Despite all this, the rope shovel remains the dominant digging machine in the shovel family. Some of the advantages in design that have been recently incorporated into some of the electrically powered rope shovels include the following: advanced direct current static power conversion, dual planetary propel drives for improving maneuverability and travel speed; electronic programmable logic controllers that replace all the mechanical logic relays previously used for sequencing the electrical system; and solid-state electrical control systems that eliminate moving parts between the high voltage alternating current power coming in and the direct current power for the motion motors.[54]

Controlled Blasting

Surface mines are using controlled blasting techniques to reduce rockfall

hazards and improve blast casting by maintaining a uniform and predictable burden. Since the bulk of the material is cast by the front row of blastholes, this burden dimension is critical to the success of the entire cast. Many mines are adapting presplit techniques to reduce rockfall hazards. The economic aspect of transitory highwalls encourage methods such as the popular air deck prosplit, low-density explosives, and decoupling techniques. The U.S. Bureau of Mines demonstrated several techniques that deal with a broad range of conditions where air decks and decoupling may be used.

REMOTE MINING

Borehole Mining

The frozen placers in Alaska contain vast deposits of columbium, gold, platinum, and tin. In the past, dredging has most often been the choice for mining these deposits. Now that most of the shallow, dredge-type deposits have been mined out, the use of conventional surface and underground methods to mine the remaining deposits would not be economical.

The U.S. Bureau of Mines-developed borehole mining system has been successfully tested in coal, oil sands, phosphate, and uranium ore. This system can remotely extract a mineral deposit through a borehole. A tool consisting of a water-jet nozzle and slurry eductor is lowered into the deposit, and the water jet erodes a cavity in the mineralized ore, which it slurrifies and pumps to the surface. The values are extracted from the slurry through settling ponds or other means, and the waste material is then returned underground by operating a similar tool in reverse.

In addition, borehole mining research is continuing in the U.S.S.R. To date, gold ore, iron, and titanium have been mined successfully using the borehole mining system.

In Situ Leach Mining

The U.S. Bureau of Mines is conducting research to develop in situ leach mining technology for oxidized copper deposits and oxidized manganese deposits. In situ leach mining offers the potential to significantly reduce production costs that would allow the economic recovery of minerals from small-, deep-, and/or low-grade mineralized deposits. In addition, the method requires significantly less surface disturbance when compared to conventional mining methods.

Preparations for an in situ copper leach mining field test are underway at the Santa Cruz site near Casa Grande, AZ. A five-spot well pattern was constructed, and a salt tracer test was conducted to obtain hydrologic leaching tests. Geologic characterization studies of the ore were also conducted. These data were used to prepare the field test design plan, and the environmental permit applications required before the in situ mining test with dilute sulfuric acid can begin.

Two manganese deposits in the Cuyuna Range of north-central Minnesota are being evaluated for in situ leach mining in the future. One core hole was drilled into each deposit to provide additional information on site geology and to provide samples for geologic characterization studies and laboratory leaching. Laboratory leaching tests with a sulfur dioxide leach manganese from the metal-bearing solution are being developed. These data will provide a basis to evaluate the technical, economic, and environmental feasibility for in situ mining these deposits.

Hot Spots Show Coal-Rock Interface

Development began on a new coal interface detection (CID) system by the U.S. Bureau of Mines. The system employs a highly sensitive, passive infrared (IR) capable of measuring the temperature changes that occur when mining machines contact different types of geological materials, such as coal, sandstone, and limestone. In a passive IR system, naturally generated, thermal IR radiation can be detected—no active IR illumination source is required. With the recent advances in sensor technology and computer-processing capabilities, researchers have been seeking an instrument to sense precisely the interface between coal and the other strata. Such an instrument would become indispensable in longwall and continuous mining, boosting productivity, reducing amounts of rock and minerals that must be removed from coal, and providing additional technology for underground automation.[55]

Automated Hoisting

One area of many underground mines that has already become automated is the shaft. Because of a hoisting accident 2 years ago, Placer Dome was forced to replace the skips, chairs, and dump in its No. 8 shaft in the Timmins Mine. Placer Dome also decided to enhance the automated ore-hoisting process.

Programmable "logic controllers" (PLC's), installed on the mine's underground water pumps in 1985, worked so well that they were also used to automate the loading pocket operation. During a 3-year, fault-free operating period, the number of 14-st skips hoisted during an 8-hour shift jumped to 152 from 127. After shaft rehabilitation during 1988, the mine now hoists 160 16-st skips per shift.[56]

Automated Train Haulage

An automated ore-handling system exists at the Golden Giant Mine in Hemlo, Ontario, Canada. Ore from the mine's ore pass system is fed through chutes into 22-st-capacity, bottom-dump ore cars on the 4335 level. The (unstaffed) PLC-equipped locomotive is controlled remotely during the loading cycle by an operator in the surface control room using video monitors. The locomotive is then placed on automatic control and hauls cars to a coarse ore bin that feeds into the underground crusher on the 4295 level and returns for another load. PLC's also monitor the ore feeder, crusher, discharge conveyor, and levels in the fine ore bin. The 4235-level loading pocket below the crusher is fully automated as is the production hoist. Having achieved a hoisting record of 6,600 st in a 24-h period, the company is now looking seriously at increasing the speed at which the 17.6-st skips are hoisted along the 3,756-ft distance to the surface.[57]

BENEFICIATION

Effect of Grinding

Effect of grinding and electrochemical interactions on the flotation of minerals was studied extensively in 1990. For example, it was found that the grinding media and environment can affect the surface properties of sulfide minerals, thus causing either improvement or deterioration in their floatability.[58]

Flotation

Froth flotation continued to be the most widely used separation process in mineral processing. In the past year, research continued to focus on the hydrodynamics within the flotation cells and the description of the bubbles in the pulp and froth

phases. Kinetic models of bubble and particle collisions were refined to more accurately portray real-world results.[59]

Rapid Flotation

The U.S. Bureau of Mines is developing a rapid flotation system. The speed of flotation is governed by the rate of bubble-particle attachment and bubble-pulp separation. In most conventional flotation cells, attaching the bubble to the fine particles is the slowest step in the flotation process, often requiring 5 to 15 minutes for completion. Intense mixing of the air bubbles and ore pulp speeds up this process, but the higher levels of agitation also disturb the relatively quiescent surface of the cell where the froth concentrates the hydrophobic minerals. The disturbance usually lowers recovery by detaching particles from the bubbles and lowers grade by allowing suspended gangue to overflow into the concentrate. In a conventional flotation cell, interaction between the agitation for rapid bubble-particle attachment and the pulp quiescence required for selective recovery of the froth make it virtually impossible to optimize one of the processes without sacrificing the effectiveness of the other. In 1990, the Bureau devised a revolutionary flotation system using discrete unit operations for bubble-particle attachment and bubble-pulp separation. The conditioned ore is pumped to the bubble-particle attachment unit where intense agitation with another stream of externally generated bubbles quickly attaches the hydrophobic particles to the bubbles. After passing through the bubble-particle attachment unit, the mixture enters a shallow tank where the mixture spreads horizontally near the top of the tank. The bubbles quickly rise to the top and overflow at the outer edge of the tank. The relatively quiet flow in the tank cleanly recovers the bubbles from the pulp, and the shallow depth of the tank allows the bubbles to separate quickly from the pulp. Using a phosphate-bearing sample, the rapid flotation system recovered 76% of the phosphate at a speed 20 times faster than a conventional flotation system using the same sample. In addition, the conventional flotation system process only recovered 65% of the phosphate. Similar test work on coal and porphyry copper ore samples demonstrated rapid flotation with acceptable product grades and recoveries. The rapid flotation circuits will be many times smaller than the current conventional flotation circuits and should cost less to construct. In addition, present facilities with limited space will be able to expand their capabilities with the rapid flotation system without enlarging their buildings.

New Phosphate Resource Produced From Waste Ponds

New reclamation techniques have yielded large quantities of dried mining waste containing high amounts of phosphate from impoundment ponds in Florida. But these wastes also contain significant amounts of undesirable contaminants such as aluminum, iron, and small amounts of radium.

The U.S. Bureau of Mines developed a way to remove most of these contaminants so that this "new" phosphate resource can be used. The Bureau's technology involves leaching phosphate values from the clay wastes using sulfuric acid as the leaching agent and methane as the solvent. Research showed that about 85% of the phosphate can be recovered in the form of a phosphoric acid suitable for fertilizer manufacture. A new flotation technique, also developed by the Bureau, enables the leach tailings to be separated efficiently from the methane-phosphoric acid product.[60]

Procedure Demonstrated to Take Valuable Metals From Sulfide Ores

The U.S. Bureau of Mines developed a procedure, based on oxidation under pressure, to recover valuable metals from sulfide ores. Cobalt, copper, nickel, and zinc, commonly found in the United States in massive sulfide ores, cannot be effectively upgraded by physical separation. They must be processed by chemical methods. These ores also contain gold and silver; however, these precious metals cannot be extracted by standard cyanide processes.

The Bureau successfully demonstrated a laboratory process to recover cobalt, copper, gold, silver, and zinc from an Oregon massive-sulfide ore. The ore is pulverized and placed in a medium-pressure vessel. With the addition of water and oxygen, the ore is heated to 392° F. The cobalt, copper, and zinc are dissolved and recovered from the solution, and the ore residue is altered so that the gold and silver can be easily extracted by cyanide solution. The use of pressure oxidation is being used by a few operations to recover gold.[61]

New Bio-Oxidation Technology

U.S. Gold Corp. produced its first gold-utilizing bacterial oxidation. The company has been a pioneer in commercializing this new technology over the past 2 years. The bio-oxidation process developed at the Tonkin Springs Mine in Nevada uses naturally occurring bacterium *Thiobacillus ferrooxidans* and pretreats refractory gold ore. The process breaks down the iron and sulfur compounds within the ore releasing the gold, which is then recovered using conventional milling methods.

Because bio-oxidation allows for development of this important class of gold deposits, it could be the technology of the nineties for the gold industry. The process should provide a lower cost in processing sulfide refractory ore and has important environmental benefits. For example, byproducts of bio-oxidation can neutralize residual cyanide in mill tailings, rendering the cyanide harmless.

The newly constructed $31 million Tonkin Springs mill has a design capacity of 1,500 st/d with a designed 90% recovery rate that should produce 50,000 oz of gold annually. This initial gold pour represents a major milestone for the company demonstrating the technical feasibility of bio-oxidation. However, the mill must still demonstrate commercial and economic viability, which is dependent on operations reaching full-scale production.[62]

Wet Milling

Minimizing a worker's exposure to asbestos fiber remains a top priority in 1990 for operators of mills that treat asbestos ore. Current Canadian regulations permit two fibers of asbestos per milliliter (ml) of air, while other countries have lowered the limit to 0.5 fibers per ml. Baie Verte Mines, a 100%-held subsidiary of Cliff Resources Corp., which operates an asbestos mine in north-central Newfoundland, Canada, thinks it has found a solution to airborne fiber—a solution that could keep the operation going for another 18 years. To recover more fiber from its ore, the company spent $18 million to construct a wet mill that in March began recovering more asbestos from the tailings stream of the existing dry mill. When that dry mill is decommissioned 3 years from now, the new mill will continue to treat asbestos tailings that have been stockpiled for the past 36 years. At a rate of 55,100 st per year, that would suffice for about 15 years of operation.

Experience in a prototype mill constructed at the Woods Reef Mine in New South Wales, Australia, in 1981 showed that occupational exposure to asbestos fiber could be maintained at less than 0.08 fibers per ml. The process was developed in a research project that began in 1977.[63]

Carbon-in-Leach With Oxygen (CILO) Cost Study

Minproc Engineers (United States) prepared a cost study to compare carbon-in-leach with oxygen (CILO) and conventional CIL circuits designed for equivalent extraction of gold. The key assumption is that CILO can reduce the retention time by a factor of four compared to CIL—something that can reportedly be demonstrated in laboratory tests for a specific ore.

The study provides capital and operating cost comparisons for the leach-absorption section of CILO and CIL circuits of 1,100, 3,310, and 5,510 st/d throughput. Costs for an open design in moderate climate conditions and for an enclosed design for more inclement weather are included for each case. Capital savings range from about $900,000 for the 1,100-st open plant to about $3.2 million for the enclosed design. The savings become increasingly significant as the capacity increases and may suggest some new options for large-tonnage, low-grade projects that are currently being considered only for heap leaching.

Operational savings are based on reduced power requirements and reduced cyanide consumption, with an allowance for oxygen costs. Projects savings are said to range from about $70,000 per year for the 1,100 st circuit to about $315,000 per year for the 5,510 st circuit.

Kamyr Inc., from whom the patented CILO process can be licensed for commercial production, suggests that the capital and operating cost savings are also compelling reasons to consider CILO for any new project. The company can provide a variety of services to process users ranging from technical assistance in process application to a complete mill.[64]

Real-Time Ore Analysis

The new model 200, offered by Outokumpu Electronics of Finland and widely used in the minerals extraction industries, was introduced to the range of Beltcon on-line analyzers. The novel feature of the model 200 is its measurement principle: the Beltcon uses X-ray fluorescence (XRF) to measure simultaneously the concentrations of any two elements from potassium to uranium.

The analyzer is able to operate on both fine and course bulk materials directly from the moving conveyor belt and is thus well suited to mineral processing and metallurgical applications. A typical use is in analysis of calcium and iron in limestone. The noncontact system is easy to install on operating conveyors without the conveyor being modified. The analyzer is above the belt; there is no contact with the moving ore stream, and no physical sampling is required.

Analysis is reportedly very rapid at 300 measurements per minute and, as each assay is based on several thousand measurements, the results obtained are described as highly reliable and accurate. A personal computer can be interfaced to the analyzer for versatile data processing. The results are available on a serial output to either a terminal and/or printer for stand-alone operation or to a personal computer for more versatile data processing. The data are also available as 4 to 20 milliamperes current outputs for recorders, controllers, etc. The control and alarm outputs allow the system to be used for direct-process control. Benefits are said to include lower production costs through improved selective loading, as well as increased efficiency and higher product quality through process stabilization.

The personal computer calculates and displays measured average analyses over the measurement period; it stores the 6,000 latest measurements, 200 shift levels, and 350 latest daily levels. These measurements are also available for statistical processing. The display shows continuously the results of the latest assays as well as cumulative shift and daily averages, indicating any trends.

The Beltcon 200 requires little maintenance as there are no moving parts, and, under normal operating conditions, no user intervention is necessary.[65]

Magnetic Separators

In 1990, Boxmag-Rapid Ltd., the Birmington, United Kingdom-based magnetic mineral separation specialist, launched a new range of high-intensity magnetic separators utilizing powerful rare-earth permanent magnets.

Designated the Magnaroll, the new separator was designed to remove weakly paramagnetic minerals or fine iron scale from nonmagnetic feed material. The feed passes over a head pulley, and nonmagnetics are thrown from the roll by centrifugal force while the magnetic particles adhere to the belt and are discharged into a separate chute. Separation flexibility is introduced by providing an adjustable splitter plate to separate the nonmagnetic-magnetic fractions and by varying the rotational speed of the Magnaroll. The head pulley is manufactured from powerful neodymium-boron-iron rare-earth magnets. The choice of two different roll diameters, 3 in for fine particle and 4 in for course materials, allows an optimum magnetic circuit to be designed for each individual mineral.

The magnetic field strength produced by the Magnaroll on the feed belt surface is usually between 9,000 and 10,000 gauss, and the exceptionally high field gradients achieved by the magnetic circuit design gives excellent separation performance, reportedly comparable to traditional induced roll magnetic separators.

Typical applications for the Magnaroll include purification of silica sand and feldspar, andalusite upgrading, and removal of iron scale from spray-dried ceramic granules. Capacities for the MR1.1000 Magnaroll, which has a feed belt width of 39 in, range from 2.2 to 11 st/h, depending on the mineral application and particle size of feed.

The Magnaroll can effectively process a wide size range of feed materials, from 1.5 in down to 1.77×10^{-3} in. This compares very favorably with the feed range to an induced roll (less than 0.1 in down to 1.77×10^{-3} in). The extra flexibility is said to have opened up new uses for high-intensity, dry magnetic separation; for example, coarse magnesite-serpentine separation.[66]

New Rare-Earth Metal Refining Method

A new method to refine rare-earth metals by means of laser purification and selective ionization was developed by researchers at the National Research Institute for Metals of the Science and Technology Agency and Nippon Steel Corp.

The process, while not new in concept, is reported as the world's first demonstration and proof of the purification concept. The new technology involves vaporizing a rare-earth metal with a beam of electrons and then directing a laser into the metal vapor to separate impure elements. The technology could enable purification of any

type of rare-earth metal simply by altering the wavelength of the laser.

In the experiment, however, efforts were directed at the metal neodymium and praseodymium was removed, considered to be the most difficult element to separate from neodymium. The experiment succeeded in reducing the amount of praseodymium in neodymium metal from 1.5% to 0.09%. Previously, a purity of 99.9% was considered the limit of refining for rare-earth metals, but the new process should permit even purer final products.[67]

HEALTH AND SAFETY

Safety Data

Preliminary injury and employment statistics compiled by the Mine Safety and Health Administration (MSHA) for 1990 showed that there were 56 mine fatalities in the Nation's metal and industrial mineral mines, eight more than in 1989. The same data showed that the average number of employees increased by only 0.5%, much less than the 4.0% average increase in 1989 and the 5.6% increase in 1988. From the MSHA data, employee-hours were shown to decrease by an early estimate of 6.6%, in contrast to 1989's increase of 2.7%. Total reported injuries decreased following an increase for 4 consecutive years, dropping to about 7.2 per 200,000 employee-hours, down from a 8.0 rate for 1989 and 7.9 in 1988. The rate of nonfatal injuries requiring lost work time was essentially the same as those in 1989 and 1988. Approximately 4.3 of such injuries occurred per 200,000 employee-hours in 1990, 4.4 in 1989 and 4.3 in 1988. All figures include independent contractors.

Legislation

The Occupational Safety and Health Administration (OSHA) revised its 1986 asbestos standard by banning smoking by workers in all areas where there is occupational exposure to asbestos; requiring employers to provide workers with literature on smoking cessation programs; issuing new requirements for respirator use; and modifying its hazard-communication program on training, labeling, and posting of warning signs. The agency also proposed reducing the permissible 8-hour time-weighted average limit to 0.1 fiber per cubic centimeter (f/cm^3); introducing work practice standards for certain occupations; requiring notification of OSHA prior to asbestos removal, demolition, or renovation; modifying hazard communication standards and project monitoring requirements; and dealing with requirements for negative-pressure enclosures.

OSHA extended a partial stay on the ruling that established exposure limits for the nonasbestiform varieties of actinolite, anthophyllite, and tremolite through November 30, 1990, while it continued to evaluate the economic impact on the mining and construction industries and whether to regulate nonasbestiform amphiboles under the standard for asbestos.

MSHA continued a review of its proposed revision to its existing asbestos standard. The proposed permissible 8-hour time-weighted average exposure limit will be reduced from 2.0 f/cm^3 to 0.2 f/cm^3 if the proposed standard is enacted.

In February 1990, OSHA proposed to reduce the Permissible Exposure Limit (PEL) for airborne cadmium to either 1 or 5 micrograms cadmium per cubic meter of air (μg/m^3). The current PEL is 100 μg/m^3 PEL for cadmium fumes and 200 μg/m^3 for cadmium dust.

OSHA held two public hearings, one in Washington, DC, in June, the other in Denver, CO, in July. These hearings were held to obtain further information on the feasibility of meeting a 1 or 5 μg/m^3 PEL for cadmium using engineering controls and/or administrative controls. The Agency was expected to reach a final decision by the second quarter of 1991.

MSHA continued to review a proposed revision to its existing talc exposure standard and proposed introducing an exposure standard for soapstone. The proposed permissible 8-hour time-weighted average exposure limit is 2.5 milligrams per cubic meter (mg/m^3) for talc (containing no asbestos), 3 mg/m^3 for respirable soapstone dust, and 6 mg/m^3 for total soapstone dust.

Human Factors

The use of extended workdays, shift lengths longer than 8 hours, received increasing attention in 1990 by the mining industry in the United States and Canada.

Despite the attractive features of these alternative work schedules, questions remain about possible safety and health risk factors associated with extended workdays in mining.

Increased fatigue, decrements in behavioral performance, increased errors, and longer exposure to airborne contaminants and environmental hazards are factors that must be considered in a 10- to 12-hour day. To address these, the Bureau initiated a human factors field research study of extended workdays in underground mining. Cooperators are an underground metal mine in western Canada and the British Columbia provincial government. The first phase of the study was completed in May 1990, while mine workers participating in the study still were on a rotating 8-hour shift schedule. The second phase of the study is scheduled for May 1991, 10 months after the workers in question changed to 12-hour shifts. The same measures will be repeated on the same subjects.[68]

Research

Ground Control, Roof Support.—The U.S. Bureau of Mines is developing improved waveform processing and tomographic image capabilities to assist in the interpretation of subsurface geologic and hydrologic features. The crosshole systems are used with advanced tomographic imaging. They permit visually opaque earth structures to be viewed by acoustic (sound-seismic) waves in a manner similar to the way computer-assisted tomography (CAT) scans view parts of the body.

The first known application of fiberglass dowels, or forepoles, in a room-and-pillar continuous mining development section was completed at the South Field Mine in Utah by the Bureau. The forepoles were installed ahead of the working face into the mine roof for distances of up to 20 ft and were held in place by a resin-type grout. Air was injected into the face and overlying strata to evaluate the tightness of the fractured rock strata before and after forepole installation. This demonstration of the use of forepoles provided access to previously inaccessible coal reserves. It also verified theoretical models that indicated that forepoling maintained the integrity of roof strata after mining.

An automated, minewide monitoring system was successfully deployed by the Bureau at the Foidel Creek Mine, Cyprus Yampa Valley Coal Corp. This system is obtaining ground and shield pressure data from 100 instruments and continuously transmitting the information to a central site. Three-dimensional computer programs

were developed to graphically display the data and permit detailed examination of stress buildup and load transfer trends as mining progresses. The system has predicted ground pressures ahead of the face for distances of up to several hundred feet. It will form the foundation for developing an effective tool for mining engineers and management to evaluate and control the ground conditions in real time.

Bureau field testing of a short-pulse radar system in a West Virginia coal mine successfully located cased and uncased boreholes 50 ft inside a block of coal. Radar penetrations of 200 ft were achieved with minimal attenuation. Experience showed that the best radar configuration from operational and analysis viewpoints involved transmitting from one side of the panel (headgate) to the other side of the panel (tailgate).

The analysis of longwall pillar stability (ALPS) method was used to size pillars in operating mines that are essential to protect critical gate entries that provide access to the face. In using the Bureau-developed ALPS method, the candidate mines have improved the safety of miners by reducing the possibility of rock falls in the gate entries. The ALPS method was formatted for personal computers and is now being distributed throughout the coal industry.

Acid Mine Drainage.—Research studies continued to evaluate the performance of constructed wetlands to accomplish passive treatment of acid mine drainage (AMD). Generally, data collected by regulatory agencies and mining companies about the performance of constructed wetlands consist of influent and effluent water chemistry. In the absence of valid flow rate measurements, it is difficult to separate the effect of the wetland from that of the dilution by fresh water. As some wetlands received inflows of surface water during storm events, dilution may be an important component of wetland performance at these sites, possibly complicating the analysis of water chemistry data.

The Bureau developed a method that allows adjustment of water chemistry data so that dilution is no longer an analytical concern. It is based on the following observations:

- Concentrations of calcium, magnesium, and sodium are commonly quite high for AMD versus fresh water; and
- These cations are not affected by wetland processes.

By calculating a dilution factor from changes in the ions, iron and magnesium concentration can be adjusted, resulting in a better evaluation of wetland performance.[69]

Rock Reinforcing Cables.—Researchers at the U.S. Bureau of Mines found that steel cables grouted into drill holes offer a safe and effective method to support the roof prior to cut-and-fill (overhand) mining. Steel cable supports recently gained popularity in conventional mining practices as a means to reinforce rock before mining it.

As each slice of ore is blasted and removed, the rock above it remains in place because it is supported by the cables. Bureau engineers found that presupporting the rock increases miners' safety and improves ore production primarily by allowing mining to take place in rock that may be difficult to support after blasting. The steel cables offer unique advantages as a support system. They are strong, able to carry about 58,000 lb of load, and since they are flexible, they are useful in even confined areas.[70]

Smart Roof-Bolt Drill.—Researchers at the Bureau developed a system that provides data needed by miners to evaluate roof conditions in a mine. Even though about 25% of the production budget of a typical coal mine is used for ground control, roof falls still occur because of the difficulty involved in detecting hazardous geological conditions.

The Bureau's system is mounted on a roof-bolt drill. This smart drill system provides the operator with real-time displays of the specific energy of drilling and drill bit position. Through the use of a microcomputer, critical drilling parameters can be instantaneously interpreted and analyzed. The operator can be informed of hazardous roof conditions about which he or she may be unaware, such as voids, inclusions, or changes in strata. Mine workers can use this information to help them decide when to install longer bolts, change spacing between bolts, or use a different bolt system.

The Bureau plans to improve the capability of the existing system by incorporating a means to automatically control drilling efficiency. As a result, equipment maintenance and downtime will be reduced, and the useful life of drilling components will be extended. Other plans include the development of computer software that can be used to achieve better drill control and that will provide additional data on rock structure. Through judicious use of sensor technology, an expert system could determine imminent failure of roof strata.[71]

Dust Control.—Airborne dust in mineral processing facilities poses health risks for plant workers. The U.S. Bureau of Mines successfully lowered the dust exposure of workers by approximately 70% during the bag-stacking process at processing plants by developing a dust-control system specifically for pallet loading. The system not only lowers dust levels, it makes bag stacking much easier for workers, thereby reducing back fatigue and injuries in this job function. The system employs a hydraulic lift table to ensure the pallet height remains constant throughout the entire bag-stacking cycle. A number of operations are presently pursuing implementing this technique at their facilities.

The system uses a push-pull ventilation technique to capture dust generated during bag stacking. A low-volume, high-velocity blower system blows a stream of air over the top layer of bags on a pallet and traps the dust. The exhaust air can then be dumped into a baghouse ventilation system or filtered before being discharged outside the mill. The system has been tested successfully at two mineral processing plants.

Reducing Worker Exposure to Silica Dust.—The health effects of exposure to respirable silica dust continued to be a major concern to the U.S. mining industry in 1990.

The Bureau investigated optimizing total mill ventilation systems. By properly designing ventilation flow patterns to sweep major contaminants, dust levels inside these facilities can be substantially lowered in a cost-effective manner. A Bureau-designed total mill ventilation system was installed at a clay operation in New York and lowered respirable dust concentrations throughout the facility by approximately 40%. This system provided 10 air changes per hour, and the total cost to purchase and install this system was less than $10,000. A second total mill ventilation system was evaluated at a silica sand operation in central Texas where the system provided approximately 30 air changes per hour. Reduction in respirable dust levels up to 80% was measured in a number of locations throughout the facility.

Diesel Breakthrough.—A breakthrough in diesel particulate control was achieved by the U.S. Bureau of Mines through the development of disposable filters used after water scrubbers. Two evaluations in operating mine sections showed a 98% reduction in diesel particulate loading in the return airway.

Also in the diesel area, field validation of the dichotomous nature of diesel particulate in mineral dust in underground coal mines progressed. Analysis of the data collected to date confirmed that the aerosol is less than 0.8 micrometer (μm) in diameter, while the diameters of mineral dust tend to be greater than 1 μm ($\approx$1/25,000 in).

During these studies, the research version of the Bureau's personal diesel aerosol sampler (PDAS) performed effectively. It accurately separated the two particulates to determine the respective mass fractions. The success of the work is attracting attention in the United States and abroad, specifically in Australia, Canada, and the United Kingdom. Because of excessive manufacturing costs of the PDAS research version, the Bureau designed and tested prototypes of a less expensive version that could be commercially manufactured for about $10.[72]

Catalytic Diesel Purifier.—A new high-performance catalytic purifier—the Englehard PTX-Ultra exhaust purifier—claims to reduce poisonous and noxious emissions from diesel-powered mining and tunneling equipment. In addition to converting hydrocarbons and carbon monoxide (CO) to water and carbon dioxide (CO_2), it is said to achieve significant reductions in sulfate and sooty fume emissions (which include soluble organic fractions or SOF's) commonly associated with diesel engines. The purifier can also be rapidly retrofitted on-site to diesel-powered equipment, such as personnel carriers, dump trucks, and front-end loaders, with engine capacities up to 1,281 in^3.

Soot and heavy hydrocarbons produced by the incomplete combustion of diesel fuel and lubricating oils, besides being a severe respiratory irritant, can also cause headaches, nausea, and dizziness which, in turn, can lead to accidents. The PTX-Ultra reportedly reduces SOF's by about 60% compared to conventional purifiers and also retards formation of sulfates, which existing systems can accelerate by as much as 10%, as well as converting gaseous hydrocarbons and CO. The purifier unit was specially designed to achieve maximum emission reduction without loss in engine efficiency and to withstand any rough handling in the tough mining and/or tunneling environment.[73]

Reducing Exposure to Diesel Exhaust Emissions.—To reduce worker exposure to diesel exhaust emissions, the U.S. Bureau of Mines successfully developed and tested several new control technologies. These developments enable the mining industry to comply with increasingly stringent health and safety standards.

Diesel engines emit both gaseous and particulate pollutants into the atmosphere, and control of these emissions is necessary to ensure a healthful work environment. Diesel particulate matter is the greatest concern because it is almost entirely respirable in size.

The Bureau, with industrial cooperators, successfully developed a disposable diesel exhaust particulate filter system. Tests in an underground coal mine showed diesel soot reductions of 95%. The filter element is similar to intake air filters used on large diesel engines. The filter material can be made of various types of treated natural or synthetic materials.

The DDEF system consists of adapters, a water trap, the filter, and canister. These components are downstream of the water scrubbers used on part 36 permissible coal mining equipment. Installation at this location takes advantage of the cool exhaust exiting the water scrubber.

A week-long study determined the effects of the disposable filter on air quality in an underground coal mine. Analysis of measurements taken in the mine indicate that diesel-generated soot was reduced by 95%. The filters have a useful service life of about 10 to 12 hours and cost about $40 each.

Sheathed Explosive.—Setting off unconfined explosive charges in gassy or dusty underground mines is prohibited by law because their detonation could cause catastrophic mine explosions or fires. However, there are advantages in using unconfined charges underground. These explosive charges can be used effectively to break up large boulders, rocks, and slabs when cleaning up roof falls. They can also be used to dislodge dangerous overhangs.

The U.S. Bureau of Mines developed a nonincendive explosive charge that will not ignite gassy or dusty atmospheres, even methane-laden air. The explosive charge effectively breaks rock in underground coal mines and can be safely fired without the use of blastholes and stemming. Firing the charge can be performed safely because the explosive is encased in a sheath of salt that disperses into a fine cloud upon firing. As the salt scatters, it acts as a flame retardant. The shock from the explosive detonation breaks the rock.

The Department of Labor's MSHA approved the device as "permissible" or legal for use in underground coal mines. An explosives manufacturer, Austin Powder Co., began marketing the commercial version of the charge in spring 1990 under the name "Sheathed Rockbuster."

Shock-Resistant Emulsion Explosive.—The U.S. Bureau of Mines, in 1990, designed a safer emulsion explosive. Emulsions are preferred in many applications because they are more powerful than traditional explosives, offer a reduced risk of being accidentally detonated, and are easy to handle. Emulsions do have some undesirable characteristics, however. When used in a delay blasting pattern in underground mines, shock waves from neighboring explosive-loaded boreholes can damage emulsion explosives to the point that they will, at best, not detonate properly, or at worst, not detonate at all. Reports from the field suggest similar events may be occurring during blasting at surface mining operations. The Bureau's new safer emulsion explosive solves this problem. The safer emulsion is resistant to shock waves and detonates properly because it contains an improved, pressure-resistant emulsion composition. In addition, the safer emulsion retains the favorable characteristics of conventional emulsion-type explosives.

The Bureau applied for a patent on this novel shock-resistant explosive and is seeking a commercial manufacturer.[74]

Rock Movement Forecasting.—A computer technique developed by the aircraft industry is being used by U.S. Bureau of Mines mining engineers and geologists to evaluate and optimize shaft designs for deep mines. The technique, called "finite-element modeling" (FEM), was adapted by Bureau scientists specifically for the mining industry. Using the FEM technique, Bureau researchers can forecast how rock in a deep mine shaft will behave. To evaluate the stability of a shaft pillar, for example, a finite-element model would be developed by entering information about three critical factors: mining geometry, premining stress state, and material properties of the rock

mass. Using this information, different shaft designs can be analyzed for safety and stability. The Bureau successfully used the FEM program to forecast the stability of a mine shaft at the Homestead Mine in Lead, SD.

Computers and Blasting.—The use of computers for scheduling, inventory control, and mine planning in 1990 expanded rapidly. Computers also saw increasing use in machine-mounted instrumentation to monitor various operating parameters onboard blasthole drills and rock-loading equipment. Related work involves using expert systems to interpret data and advise on machine maintenance timing and troubleshooting procedures.

The application of explosive casting technology to surface mining continued to grow. Two companies reported that, even in geologically disturbed overburden, modified drilling patterns and presplitting resulted in reduced operating costs with dramatic improvements in highway stability and safety.[75]

Computer-Aided Fire Detection.—Based on a Bureau-developed, patent-pending process algorithm, a unique computer program was prepared during 1990 to quickly determine the location of a fire in a complex network of mine workings. The computer program utilizes real-time data from a network of in-mine fire detection devices, along with the output from a mine ventilation simulator, to calculate the probable location of a fire. In-mine tests of the complete system are planned to validate the process.

Mine Fire Modeling.—A Bureau-developed computer simulation program called "MFIRE," originally released in 1988, underwent various upgrades to improve performance and ease of use in 1990. The program is an enhanced ventilation network simulator that enables quantitative evaluation of complex interactions between mine fires and mine ventilation systems. The program is unique among ventilation simulators in that it calculates natural ventilation forces, due both to natural strata heat and fires; identifies reversals and recirculation paths; tracks the production and time-dependent spread of combustion products; and permits analysis of multiple, overlapping transient events involving the ventilation system and mine fires. Upgrades completed during 1990 include increasing the range of conditions that the program can simulate and increasing the accuracy of the predictions of the program.

New Communication System Enhances Mine Safety.—The system developed and patterned on novel Bureau-developed technology is hailed as a breakthrough in underground mine communications in that it can transmit messages through the Earth, from surface to locations underground without cables and without radio aerial networks. Known as PED (Personal Emergency Device), in its most basic form this innovative system consists of four elements: a personal computer, a transmitter, a single-surface aerial, and a portable receiving unit.

To send messages, they are typed into the personal computer—each message can be up to 32 characters long. Once created, the message is sent by transmitter in the form of low-frequency electromagnetic waves. By linking additional personal computers into the system, messages can be sent from numerous mine locations—both above and below ground. Messages can be directed to an individual, to a group (e.g., blasting crew or longwall face crew), or simultaneously to all personnel.

The PED receiving unit is integrated with the miner's battery pack—already carried for his or her cap lamp. When a message is received, the cap lamp flashes over 10 seconds; the miner can then read the message from a liquid crystal display on top of the battery pack.

PED is reportedly suitable for both coal (it is intrinsically safe) and hard-rock mines and is very durable, having been designed for long-term use in physically arduous environments.[76]

Safety at Surface Mining Dump Points.—A specialized computer simulation program that models surface mine dump points was completed and released during 1990. The software, "INSLOPE3," is unique in that it accounts for the dynamic loads imparted by haulage trucks operating near the dump point slope under the surcharge loading of the truck. Distribution of the program is pending completion of a user manual, which is scheduled for release in 1991.

Human Factors Research to Prevent Groundfall Accidents.—In most years, roof falls are the leading cause of fatal accidents in the underground coal mining industry. During the 5-year period 1985-89, 92 coal miners were killed by falls and more than 4,000 miners were injured. According to MSHA's accident investigation reports, 47% of the 92 victims of fatal roof fall accidents were in an area of unsupported roof at the time they were killed. One cause of these accidents relates to the problem of properly positioning roof bolting machines prior to installing new rows of bolts. An employee at a mine in eastern Ohio suggested welding flexible wire antennas onto one of the support pads of the bolter's temporary roof support system. These antennas serve as a convenient gauge to determine if the next row of bolts will be spaced the appropriate distance from the rib and from the last row of bolts bordering the area of unsupported roof.

Portable Alarm.—A new handheld, three-gas portable alarm designed for combustible gas, oxygen, and toxic gas monitoring was made available from Mine Safety Appliances Co. (MSA). The MiniGard III Portable Alarm is battery-operated, can be handheld or worn on a belt, and is designed to detect combustible gas, oxygen, and either hydrogen sulfide or carbon monoxide. It uses a microcomputer and state-of-the-art electronics to provide full-function capabilities, according to MSA. Its compact size (7 by 3.5 by 1.7 in) makes it suitable for confined space applications. The alarm features three diffusion-type sensors with concentrations of gases and vapors shown individually on an easy-to-read liquid crystal display. The display can scroll through the three channels or be locked on one, but all three gases are monitored simultaneously regardless of display setting. An earphone or optional remote alarm module is available for use in high-noise environments. A common audible and visual alarm alerts the user of dangerous gas and oxygen concentrations. When in the alarm mode, a descriptor activates in the display to indicate the type of alarm. Combustible gas calibrations are either general-purpose 0 to 100% Lower Explosive Limit pentane-in-air, or 0 to 5% methane (CH_4) in a methane-air mixture for mining applications. For toxic gas, the alarm can be selected with either a 0 to 50 parts per million (ppm) hydrogen sulfide sensor or with a 0 to 500 ppm carbon monoxide sensor. All alarms indicate 0% to 25% oxygen.[77]

Contractor Training

Dependence on using contractor personnel to perform a variety of production, extraction, and support services throughout the mining industry is increasing.

Analysis of accident and/or injury statistics for the past 8 years indicated several trends among independent contractors in the mining industry. The most alarming one is the fatality incident rate (calculated from fatality figures and normalized on the basis of 200,000 hours worked). This rate is significantly higher for contractors than for operators in both coal and metal-nonmetal mining. The fatality incident rate for contractors at coal mines averages almost twice that for operators, and the rate for contractors at metal-nonmetal mines is almost five times as great. Further analysis shows that four major accident types account for 70% of these fatalities. They include powered haulage, machinery, slips and/or falls, and electrical.

The fatal injury trend has compelled regulatory and company personnel to look at existing standards to deal with health and safety training. Policymakers and safety practitioners agree that current 30 CFR training regulations designed for mining company employees are not appropriate for the myriad of contractors and agents hired by operators to perform various services on-site.

MSHA Crackdown on Mine Fatalities

MSHA developed a program to identify high-hazard metal mines so necessary safety corrections can be made. As a part of its spotlight on safety, MSHA worked at improving accountability and strengthening the investigations unit.

A decision was made to expand the upgrading of MSHA's enforcement capability to the metal and nonmetal sector after evaluating an internal review of the Agency's performance preceding a coal mine explosion in 1989 that killed 10 Kentucky miners. The review listed several "shortcomings" of MSHA personnel, including weak enforcement at the mine where the explosion occurred.

Hoping to prevent similar disasters, MSHA called for closer monitoring of mines in the United States. "It's our intention to have a parallel program for metal and nonmetal mines," MSHA confirmed. Based on MSHA statistics, there is room for safety improvements in the metal industry.[78] Both the number of coal and noncoal mining facilities and the rate of fatalities per total hours worked increased in the first half of 1990 compared to the same period last year.

Twenty-eight metal and nonmetal (noncoal) miners died in accidents in the first 6 months of 1990 compared with 25 for the same period in 1989. The rate of fatal injuries in metal and nonmetal mining through June 1990 was 0.03 per 200,000 employee-hours compared with 0.02 for 1989.

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TABLE 1

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES, BY TYPE

(Million short tons)

Type and year	Surface			Underground			All mines[1]		
	Crude ore	Waste	Total[1]	Crude ore	Waste	Total[1]	Crude ore	Waste	Total[1]
Metals:									
1985	411	499	911	48	9	57	459	508	968
1986	418	615	1,030	52	7	59	470	622	1,090
1987	489	825	1,310	43	6	49	532	831	1,360
1988	[r]637	951	[r]1,590	31	6	37	[r]668	957	[r]1,620
1989	799	1,110	1,910	50	5	55	849	1,120	1,970
Industrial minerals:									
1985[2]	1,260	450	1,710	54	2	56	1,320	452	1,770
1986[3]	1,130	380	1,510	34	1	35	1,160	380	1,540
1987[2]	1,430	452	1,880	77	1	78	1,510	453	1,960
1988[3]	1,210	366	1,580	34	([4])	34	1,250	366	1,610
1989[2]	1,550	774	2,330	63	2	65	1,620	776	2,390
Total metals and industrial minerals:[1]									
1985	1,670	950	2,620	102	11	113	1,770	961	2,740
1986	1,550	995	2,540	86	7	93	1,630	1,000	2,630
1987	1,920	1,280	3,200	120	7	126	2,040	1,280	3,320
1988	1,990	1,320	3,310	65	6	72	2,050	1,320	3,380
1989	2,350	1,890	4,240	113	8	120	2,470	1,890	4,360

[r]Revised.

[1]Data may not add to totals shown because of independent rounding.

[2]Includes industrial sand and gravel. Construction sand and gravel data were not available for 1985, 1987, and 1989 because of biennial canvassing.

[3]Crushed and broken and dimension stone data were not available for 1986 and 1988 because of biennial canvassing.

[4]Less than 1/2 unit.

TABLE 2[1]

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES[2] IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

(Thousand short tons)

Commodity	Surface			Underground			All mines[3]		
	Crude ore	Waste	Total[3]	Crude ore	Waste	Total[3]	Crude ore	Waste	Total[3]
METALS									
Bauxite	951	W	951	—	—	—	951	W	951
Copper	300,000	334,000	634,000	4,730	146	4,880	305,000	334,000	639,000
Gold:									
Lode	214,000	566,000	780,000	13,400	3,180	16,500	227,000	569,000	796,000
Placer	13,800	26,800	40,500	—	—	—	13,800	26,800	40,500
Iron ore	206,000	108,000	31,400	W	W	W	206,000	108,000	314,000
Lead	W	W	W	8,550	W	8,550	8,550	W	8,550
Silver	12,900	35,600	48,400	3,430	781	4,210	16,300	36,300	52,700
Titanium	7,900	W	7,900	—	—	—	7,900	W	7,900
Zinc	—	—	—	5,530	W	5,530	5,530	W	5,530
Other[4]	44,400	40,900	85,300	14,000	1,190	15,200	58,400	42,100	101,000
Total metals[3]	799,000	1,110,000	1,910,000	49,600	5,300	54,900	849,000	1,120,000	1,970,000
INDUSTRIAL MINERALS									
Abrasives[5]	87	W	87	W	—	W	87	W	87
Barite	320	—	320	—	—	—	320	—	320
Clays	85,400	50,800	109,000	270	4	274	58,700	50,800	109,000
Diatomite	731	W	731	—	—	—	731	W	731
Feldspar	721	—	721	—	—	—	721	W	721
Gypsum	16,600	W	16,600	1,670	W	1,670	18,200	W	18,200
Iron oxide pigments (crude)	31	—	31	—	—	—	31	—	31
Mica (scrap)	208	109	317	—	—	—	208	109	317
Perlite	842	W	842	W	—	W	842	W	842
Phosphate rock	167,000	412,000	579,000	W	W	W	167,000	412,000	579,000
Potash	W	—	W	969	—	969	969	—	969
Pumice[6]	561	56	617	—	—	—	561	56	617
Salt	4,330	—	4,330	12,800	—	12,800	17,200	—	17,200
Sand and gravel	33,000	273	33,300	—	—	—	33,000	273	33,300
Soda ash	—	—	—	16,300	W	16,300	16,300	W	16,300
Stone:									
Crushed and broken	1,190,000	97,500	1,290,000	30,300	212	30,500	1,220,000	97,700	1,320,000
Dimension	3,470	1,430	4,900	W	—	W	3,470	1,430	4,900
Talc, soapstone, and pyrophyllite	1,360	W	1,360	W	W	W	1,360	W	1,360
Vermiculite	307	W	307	—	—	—	307	W	307
Other[7]	76,800	212,000	288,000	650	2,340	2,890	77,400	214,000	291,000
Total industrial minerals[3]	1,550,000	774,000	2,330,000	62,900	2,450	65,400	1,620,000	776,000	2,390,000
Grand total[3]	2,350,000	1,890,000	4,240,000	113,000	7,750	120,000	2,470,000	1,890,000	4,360,000
STATE									
Alabama	35,100	4,550	39,700	W	W	W	35,100	4,550	36,700
Alaska	11,500	20,700	32,200	W	W	W	11,500	20,700	32,200
Arizona	203,000	189,000	392,000	190	110	301	203,000	189,000	392,000
Arkansas	23,000	6,980	29,900	—	—	—	23,000	6,980	29,900
California	89,900	73,400	163,000	375	21	395	90,300	73,500	164,000
Colorado	7,800	1,900	9,700	10,600	175	10,700	18,400	2,080	20,400
Connectcut	11,900	1,060	12,900	—	—	—	11,900	1,060	12,900
Florida	239,000	376,000	616,000	—	—	—	239,000	376,000	616,000
Georgia	62,400	13,800	76,200	W	—	W	62,400	13,800	76,200

See footnotes at end of table.

TABLE 2[1]—Continued

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES[2] IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

(Thousand short tons)

Commodity	Surface			Underground			All mines[3]		
	Crude ore	Waste	Total[3]	Crude ore	Waste	Total[3]	Crude ore	Waste	Total[3]
STATE—Continued									
Hawaii	6,210	523	6,740	—	—	—	6,210	523	6,740
Idaho	11,800	18,700	30,500	1,240	744	1,980	13,100	19,400	32,500
Illinois	66,000	6,040	72,100	995	21	1,020	67,000	6,060	73,100
Indiana	38,800	4,060	42,800	728	—	728	39,500	4,060	43,600
Iowa	30,300	4,240	34,500	993	7	1,000	31,300	4,250	35,500
Kansas	18,100	1,860	20,000	1,690	W	1,690	19,800	1,860	21,700
Kentucky	37,300	3,860	41,100	12,200	85	12,200	49,400	3,940	53,400
Louisiana	6,010	487	6,500	4,550	—	4,550	10,600	487	11,100
Maine	1,650	179	1,830	—	—	—	1,650	179	1,830
Maryland	27,700	2,600	30,300	W	W	W	27,700	2,600	30,300
Massachusetts	12,100	1,100	13,200	—	—	—	12,100	1,100	13,200
Michigan	97,200	64,200	161,000	5,220	W	5,220	102,000	64,200	167,000
Minnesota	164,000	51,800	216,000	—	—	—	164,000	51,800	216,000
Mississippi	2,480	1,310	3,790	—	—	—	2,480	1,310	3,790
Missouri	52,500	5,700	58,200	11,100	310	11,400	63,600	6,010	69,600
Montana	49,500	47,300	96,800	13,300	396	13,700	62,800	47,700	111,000
Nebraska	3,280	460	3,710	W	W	W	3,250	460	3,710
Nevada	185,000	469,000	653,000	345	628	973	185,000	469,000	654,000
New Hampshire	911	144	1,050	—	—	—	911	144	1,050
New Jersey	22,300	1,790	24,100	—	—	—	22,300	1,790	24,100
New Mexico	60,600	103,000	163,000	2,680	232	2,910	63,300	103,000	166,000
New York	40,800	4,060	44,800	4,610	W	4,610	45,400	4,060	49,400
North Carolina	68,700	45,100	114,000	—	—	—	68,700	45,100	114,000
Ohio	52,800	7,200	60,000	3,630	W	3,630	56,400	7,200	63,600
Oklahoma	30,400	7,940	38,300	—	—	—	30,400	7,940	38,300
Oregon	19,000	2,470	21,400	40	7	47	19,000	2,480	21,500
Pennsylvania	93,500	8,590	102,000	2,170	15	2,180	95,700	8,600	104,000
Rhode Island	1,280	100	1,380	—	—	—	1,280	100	1,380
South Carolina	35,400	8,520	43,900	—	—	—	35,400	8,520	43,900
South Dakota	9,180	12,800	22,000	1,840	2,430	4,260	11,000	15,200	26,200
Tennessee	58,500	12,000	70,500	10,400	250	10,700	68,900	12,300	81,200
Texas	83,400	13,800	97,200	666	W	666	84,100	13,800	97,900
Utah	53,900	67,700	122,000	133	W	133	54,000	67,700	122,000
Vermont	3,600	365	3,960	W	—	W	3,600	365	3,960
Virginia	66,100	6,240	72,400	W	W	W	66,100	6,240	72,400
Washington	14,000	1,310	15,300	W	W	W	14,000	1,310	15,300
West Virginia	10,100	1,070	12,000	W	W	W	10,900	1,070	12,000
Wisconsin	28,100	2,220	30,300	—	—	—	28,100	2,220	30,300
Wyoming	22,100	17,700	39,800	16,300	W	16,300	38,400	17,700	56,100
Undistributed[8]	83,500	191,000	274,000	6,650	2,320	8,970	90,200	193,000	283,000
Grand total[3]	2,350,000	1,890,000	4,240,000	113,000	7,750	120,000	2,470,000	1,890,000	4,360,000

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]This table is a compilation of previous Minerals Yearbook tables 2 and 3. Data have been compiled and reorganized.
[2]Excludes materials from wells, ponds, or pumping operations.
[3]Data may not add to totals shown because of independent rounding.
[4]Includes beryllium, magnesium, mercury, molybdenum, platinum-group metals, tin, tungsten, uranium, zinc, zirconium, and metal items indicated by symbol W.
[5]Includes abrasive stone and millstones.
[6]Excludes volcanic cinder and scoria.
[7]Includes aplite, asbestos, boron minerals, fluorspar, graphite (natural), kyanite, magnesite, marl (greensand), olivine, soda ash, and industrial minerals indicated by symbol W.
[8]Includes Delaware, North Dakota, and States items indicated by symbol W.

TABLE 3[1]

VALUE OF PRINCIPAL MINERAL PRODUCTS AND BYPRODUCTS OF SURFACE AND UNDERGROUND ORES MINED IN THE UNITED STATES IN 1989

(Value per ton)

Ore	Surface			Underground			All mines		
	Principal mineral product	By-product	Total	Principal mineral product	By-product	Total	Principal mineral product	By-product	Total
METALS									
Bauxite	$13.52	W	$13.52	—	—	—	$13.52	W	$13.52
Copper	11.70	$1.72	13.42	$46.46	$1.66	$48.12	12.27	$1.72	13.99
Gold:									
Lode	15.43	1.15	16.58	9.51	1.94	11.45	14.90	1.22	16.12
Placer	5.08	—	5.09	—	—	—	5.08	—	5.09
Iron ore	8.03	—	8.03	W	W	W	8.03	—	8.03
Lead	—	—	—	32.15	38.04	70.18	32.15	38.04	70.18
Silver	4.71	7.44	12.15	25.18	18.01	43.19	9.33	9.82	19.16
Titanium	5.99	W	12.97	—	—	—	5.99	W	12.97
Zinc	—	—	—	48.04	.99	49.03	48.04	.99	49.03
Average, metals[2]	10.88	1.12	11.99	24.32	8.30	32.63	11.77	1.59	13.36
INDUSTRIAL MINERALS									
Abrasives[3]	20.57	—	20.57	W	—	W	20.57	—	20.57
Barite	39.45	—	39.45	—	—	—	39.45	—	39.45
Clays	27.85	5.09	32.94	W	W	W	27.85	5.09	32.94
Diatomite	101.06	—	101.06	—	—	—	101.06	—	101.06
Feldspar	31.43	W	35.12	—	—	—	31.43	W	35.12
Gypsum	6.97	W	6.97	7.29	—	7.29	7.00	W	7.00
Iron oxide pigments (crude)	91.09	—	91.09	—	—	—	91.09	—	91.09
Mica (scrap)	19.85	—	19.85	—	—	—	19.85	—	19.85
Perlite	12.35	—	12.35	W	—	W	12.35	—	12.35
Phosphate rock	5.09	—	5.09	W	W	W	5.09	—	5.09
Potash	W	—	W	153.50	—	153.50	153.50	—	153.50
Pumice[4]	17.51	—	17.51	—	—	—	17.51	—	17.51
Salt	10.45	W	10.45	16.49	W	16.49	14.97	W	14.97
Sand and gravel	12.45	.43	12.88	—	—	—	12.45	.43	12.88
Soda ash	—	—	—	41.43	—	41.43	41.43	—	41.43
Stone:									
Crushed and broken	4.36	.02	4.38	5.39	—	5.39	4.39	.02	4.40
Dimension	56.76	1.12	57.88	W	—	W	56.76	1.12	57.88
Talc, soapstone, and pyrophyllite	18.56	W	18.56	W	W	W	18.56	W	18.56
Vermiculite	105.93	W	105.93	—	—	—	105.93	W	105.93
Average, industrial minerals[2]	6.12	.35	6.47	22.94	4.69	27.63	6.78	.52	7.30
Average, industrial minerals (excluding sand and gravel and stone)[2]	11.82	1.65	13.47	39.07	9.06	48.13	14.50	2.38	16.87
Average, metals and industrial minerals[2]	7.69	.60	8.29	23.57	6.35	29.92	8.46	.88	9.34
Average, metals and industrial minerals (excluding sand and gravel and stone)[2]	11.15	1.27	12.41	29.92	8.59	38.51	12.57	1.82	14.39

W Withheld to avoid disclosing company proprietary data.
[1]This table had been table 4 in previous issues of the Minerals Yearbook.
[2]Includes unpublished data.
[3]Includes abrasive stone and millstones.
[4]Excludes volcanic cinder and scoria.

TABLE 4[1]

CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

(Percent)

Commodity	Crude ore		Total material	
	Surface	Underground	Surface	Underground
METALS				
Bauxite	100.0	—	100.0	—
Copper	98.4	1.6	99.2	0.8
Gold:				
Lode	94.1	5.9	97.9	2.1
Placer	100.0	—	100.0	—
Iron ore	[2]100.0	W	[2]100.0	W
Lead	W	[3]100.0	W	[3]100.0
Silver	79.0	21.0	92.0	8.0
Titanium	100.0	—	100.0	—
Zinc	—	100.0	—	100.0
Average, metals[4]	94.2	5.8	87.2	12.8
INDUSTRIAL MINERALS				
Abrasives[5]	[2]100.0	W	[2]100.0	W
Barite	100.0	—	100.0	—
Clays	99.5	.5	99.7	.3
Diatomite	100.0	—	100.0	—
Feldspar	100.0	—	100.0	—
Gypsum	90.9	9.1	94.2	5.8
Iron oxide pigments (crude)	100.0	—	100.0	—
Mica (scrap)	100.0	—	100.0	—
Perlite	[2]100.0	W	[2]100.0	W
Phosphate rock	[2]100.0	W	[2]100.0	W
Potash	W	[3]100.0	W	[3]100.0
Pumice[6]	100.0	—	100.0	—
Salt	25.2	74.8	25.2	74.8
Sand and gravel	100.0	—	100.0	—
Soda ash	—	100.0	—	100.0
Stone:				
Crushed and broken	97.5	2.5	97.7	2.3
Dimension	[2]100.0	W	[2]100.0	W
Talc, soapstone, and pyrophyllite	[2]100.0	W	[2]100.0	W
Vermiculite	100.0	—	100.0	—
Average, industrial minerals[4]	96.1	3.9	97.3	2.7
Average, metals and industrial minerals[4]	95.4	4.6	97.2	2.8
STATE				
Alabama	[2]100.0	W	[2]100.0	W
Alaska	[2]100.0	W	[2]100.0	W
Arizona	99.9	.1	99.9	.1
Arkansas	100.0	—	100.0	—
California	99.6	.4	99.8	.2
Colorado	42.5	57.5	47.5	52.5
Connectcut	100.0	—	100.0	—
Florida	100.0	—	100.0	—
Georgia	[2]100.0	W	[2]100.0	W

See footnotes at end of table.

TABLE 4[1]—Continued

CRUDE ORE AND TOTAL MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

(Percent)

Commodity	Crude ore		Total material	
	Surface	Underground	Surface	Underground
STATE—Continued				
Hawaii	100.0	—	100.0	—
Idaho	90.5	9.5	93.9	6.1
Illinois	98.5	1.5	98.6	1.4
Indiana	98.2	1.8	98.3	1.7
Iowa	96.8	3.2	97.2	2.8
Kansas	91.5	8.5	92.2	7.8
Kentucky	75.4	24.6	77.1	22.9
Louisiana	56.9	43.1	58.8	41.2
Maine	100.0	—	100.0	—
Maryland	[2]100.0	W	[2]100.0	W
Massachusetts	100.0	—	100.0	—
Michigan	[2]100.0	W	[2]100.0	W
Minnesota	100.0	—	100.0	—
Mississippi	100.0	—	100.0	—
Missouri	82.5	17.5	83.6	16.4
Montana	78.8	21.2	87.6	12.4
Nebraska	[2]100.0	W	[2]100.0	W
Nevada	99.8	.2	99.9	.1
New Hampshire	100.0	—	100.0	—
New Jersey	100.0	—	100.0	—
New Mexico	95.8	4.2	98.2	1.8
New York	[2]100.0	W	[2]100.0	W
North Carolina	100.0	—	100.0	—
North Dakota	W	[3]100.0	W	[3]100.0
Ohio	[2]100.0	W	[2]100.0	W
Oklahoma	100.0	—	100.0	—
Oregon	99.8	.2	99.8	.2
Pennsylvania	97.7	2.3	97.9	2.1
Rhode Island	100.0	—	100.0	—
South Carolina	100.0	—	100.0	—
South Dakota	83.3	16.7	83.7	16.3
Tennessee	84.8	15.2	86.8	13.2
Texas	[2]100.0	W	[2]100.0	W
Utah	99.8	.2	99.9	.1
Vermont	[2]100.0	W	[2]100.0	W
Virginia	[2]100.0	W	[2]100.0	W
Washington	[2]100.0	W	[2]100.0	W
West Virginia	[2]100.0	W	[2]100.0	W
Wisconsin	100.0	—	100.0	—
Wyoming	[2]100.0	W	[2]100.0	W
Average, States[4]	95.4	4.6	97.2	2.8

W Withheld to avoid disclosing company proprietary data; included with "Surface" or "Underground."

[1]This table is a compilation of previous Minerals Yearbook tables 5 and 6. Data have been compiled and reorganized.

[2]Includes underground; the Bureau of Mines is not at liberty to publish separately.

[3]Includes surface; the Bureau of Mines is not at liberty to publish separately.

[4]Includes unpublished data.

[5]Includes abrasive stone and millstones.

[6]Excludes volcanic cinder and scoria.

TABLE 5[1]

NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES[2] IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

Commodity	Total number of mines	Less than 1,000 tons	1,000 to 10,000 tons	10,000 to 100,000 tons	100,000 to 1,000,000 tons	1,000,000 to 10,000,000 tons	More than 10,000,000 tons
			METALS				
Bauxite	4	—	—	2	2	—	—
Copper	24	—	2	2	2	6	12
Gold:							
Lode	117	4	9	17	38	46	3
Placer	26	5	4	9	5	3	—
Iron ore	23	1	1	6	6	2	7
Lead	13	—	1	1	8	3	—
Silver	13	—	1	2	5	5	—
Titanium	4	—	—	1	2	1	—
Zinc	9	—	—	1	6	2	—
Others[3]	38	15	6	6	5	4	2
Total metals	271	25	24	47	79	72	24
			INDUSTRIAL MINERALS				
Abrasives[4]	6	2	—	4	—	—	—
Barite	17	1	6	5	5	—	—
Clays	737	35	142	411	146	3	—
Diatomite	11	—	2	7	2	—	—
Feldspar	14	—	1	11	2	—	—
Gypsum	65	1	6	13	44	1	—
Iron oxide pigments (crude)	3	1	1	1	—	—	—
Mica (scrap)	12	—	8	3	1	—	—
Perlite	9	—	2	4	3	—	—
Phosphate rock	23	—	—	—	5	13	5
Potash	6	—	—	2	4	—	—
Pumice[5]	18	—	5	6	7	—	—
Salt	28	—	1	5	16	6	—
Sand and gravel	160	2	9	67	79	3	—
Soda ash	5	—	—	—	—	5	—
Stone:							
Crushed and broken	4,065	236	463	1,406	1,679	280	1
Dimension	487	282	123	79	3	—	—
Talc, soapstone, pyrophyllite	28	2	4	16	6	—	—
Vermiculite	6	—	—	5	1	—	—
Others[6]	181	11	126	51	-10	2	1
Total industrial minerals	5,881	573	899	2,096	1,993	313	7
Grand total	6,152	598	923	2,143	2,072	385	31
			STATE				
Alabama	105	—	18	26	48	13	—
Alaska	34	2	7	12	10	3	—
Arizona	73	3	10	31	15	6	8
Arkansas	74	3	11	23	32	5	—
California	318	47	66	109	70	26	—
Colorado	89	3	22	41	20	3	—
Connecticut	26	1	1	10	10	4	—
Florida	152	1	2	37	71	37	4
Georgia	214	2	29	79	85	19	—

See footnotes at end of table.

TABLE 5[1]—Continued

NUMBER OF DOMESTIC METAL AND INDUSTRIAL MINERAL MINES[2] IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

Commodity	Total number of mines	Less than 1,000 tons	1,000 to 10,000 tons	10,000 to 100,000 tons	100,000 to 1,000,000 tons	1,000,000 to 10,000,000 tons	More than 10,000,000 tons
			STATE—Continued				
Hawaii	24	—	4	8	11	1	—
Idaho	73	1	12	35	21	4	—
Illinois	247	57	16	75	85	14	—
Indiana	117	3	10	25	72	7	—
Iowa	336	5	63	185	80	3	—
Kansas	161	10	26	73	52	—	—
Kentucky	107	—	2	25	72	7	1
Louisiana	25	—	1	8	14	2	—
Maine	15	—	3	7	5	—	—
Maryland	46	2	6	13	14	11	—
Massachusetts	36	—	5	6	22	3	—
Michigan	70	2	6	14	32	14	2
Minnesota	68	2	11	25	23	2	5
Mississippi	31	—	3	22	6	—	—
Missouri	401	2	98	175	112	14	—
Montana	74	16	12	15	16	13	2
Nebraska	21	4	3	8	5	1	—
Nevada	109	5	11	29	36	25	3
New Hampshire	14	—	3	8	3	—	—
New Jersey	38	—	5	10	17	6	—
New Mexico	90	22	19	28	18	1	2
New York	126	11	13	23	71	8	—
North Carolina	166	4	26	49	70	16	1
Ohio	192	6	22	50	100	14	—
Oklahoma	92	4	10	19	57	2	—
Oregon	231	27	35	136	32	1	—
Pennsylvania	252	10	20	58	148	16	—
Rhode Island	6	—	—	3	3	—	—
South Carolina	59	1	17	3	29	9	—
South Dakota	184	153	7	10	10	4	—
Tennessee	164	3	8	36	101	16	—
Texas	336	25	39	129	126	17	—
Utah	49	1	6	23	13	5	1
Vermont	43	5	11	14	13	—	—
Virginia	135	3	5	28	80	19	—
Washington	221	80	25	76	40	—	—
West Virginia	49	—	4	19	24	2	—
Wisconsin	313	9	79	171	50	4	—
Wyoming	256	62	103	74	10	6	1
Undistributed[7]	90	1	8	60	18	2	1
Total, States	6,152	598	923	2,173	2,072	385	31

[1]This table had been table 7 in previous issues of the Minerals Yearbook. In addition, a breakout of data by State is included.
[2]Excludes wells, ponds, or pumping operations.
[3]Includes beryllium, magnesium metal, mercury, molybdenum, platinum-group metals, tin, tungsten, uranium, and zirconium.
[4]Includes abrasive stone and millstones.
[5]Excludes volcanic cinder and scoria.
[6]Includes aplite, asbestos, boron, fluorspar, graphite, kyanite, magnesite, merl (greensand), olivine, pyrite, and wollastonite.
[7]Includes Delaware, North Dakota, and undistributed data.

TABLE 6[1]

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL[2] MINES IN THE UNITED STATES IN 1989, IN ORDER OF OUTPUT OF CRUDE ORE

Mine	State	Operator	Commodity	Mining method
		METALS		
Smokey Valley Common Operation	Nevada	Round Mountain Gold Corp.	Lode gold	Open pit.
Carlin Mines Complex	do.	Newmont Gold Co.	do.	Do.
Mintac	Minnesota	USX Corp.	Iron ore	Do.
Morenci	Arizona	Phelps Dodge Corp.	Copper	Do.
Bingham Canyon	Utah	Kennecot, Utah Copper Corp.	do.	Do.
Tyrone	New Mexico	Phelps Dodge Corp. and Burro Chief Copper Co.	do.	Do.
Sierrita	Arizona	Cyprus Sierrita Corp.	do.	Do.
Hibbing	Minnesota	Hibbing Taconite Co.	Iron ore	Do.
Empire	Michigan	Empire Iron Mining Partnership	do.	Do.
Erie	Minnesota	LTV Steel Mining Co.	do.	Do.
Bagdad	Arizona	Cyprus Bagdad Copper Co.	Copper	Do.
Pinto Valley	do.	Pinto Valley Copper Corp.	do.	Do.
Inspiration	do.	Cyprus Miami Mining Corp.	do.	Do.
Tilden	Michigan	Tilden Magnetite Partnership	Iron ore	Do.
East Berkeley Pit	Montana	Montana Resources Inc.	Molybdenum	Do.
National Steel Pellet Complex Project—Itasca	Minnesota	National Steel Pellet Co.	Iron ore	Do.
Continental	Montana	Montana Resources Inc.	Copper	Do.
San Manuel	Arizona	Magma Copper Co.	do.	Do.
Chino	New Mexico	Phelps Dodge Corp.	do.	Do.
Thunderbird	Minnesota	Eveleth Mines	Iron ore	Do.
Ray	Arizona	ASARCO Incorporated	Copper	Do.
Sleeper	Nevada	Amax Gold Inc.	Lode gold	Do.
Zortman-Landusky	Montana	Pegasus Gold Inc.	do.	Do.
Eisenhower	Arizona	ASARCO Incorporated	Molybdenum	Do.
Mission Complex	do.	do.	Copper	Do.
		INDUSTRIAL MINERALS[3]		
Grand Rivers	Kentucky	Reed Crushed Stones Co., Inc.	Stone	Open quarry.
Calcite	Michigan	Michigan Mineral Associates	do.	Do.
Cook	Illinois	General Dynamics Corp.	do.	Do.
Stoneport	Michigan	Presque Isle Corp.	do.	Do.
McCook	Illinois	Vulcan Materials Co.	do.	Do.
FEC Hialea	Florida	Rinker Materials Corp.	do.	Do.
Pennsuco	do.	Tarmac America Inc.	do.	Dredging.
Beckman	Texas	Redland Stone Products	do.	Open quarry.
Suwanne	Florida	Occidental Chemical Agricultural Products, Inc.	Phosphate rock	Open pit.
Lee Creek	North Carolina	Texasgulf Chemical Co.	do.	Dredging.
Fort Green	Florida	Agrico Chemical Co.	do.	Open pit.
White Rock	do.	Vecellio and Grogan Inc.	Stone	Open quarry.
Georgetown	Texas	Texas Crushed Stone Co.	do.	Do.
Nichols	Florida	Mobil Oil Corp.	Phosphate rock	Open pit.
St. Genevieve	Missouri	Tower Rock Stone Co.	Stone	Open quarry.
New Braunfels	Texas	Parker Bros and Co	do.	Do.
Payne Creek	Florida	Agrico Chemical Co.	Phosphate rock	Open pit.
Oro Grande	California	Riverside Cement Co.	Stone	Open quarry.
Cape Sandy	Indiana	Mulzer Crushed Stone Co., Inc.	do.	Do.
Ravena	New York	Blue Circle Atlantic Inc.	do.	Do.
Mount Hope	New Jersey	Mount Hope Rock Products Inc.	do.	Do.
Frederick	Maryland	Genstar Stone Products Co.	do.	Do.
Granite	South Carolina	Bad Creek Constructors	do.	Do.
Manassas	Virginia	Vulcan Materials Co.	do.	Do.
Permanen	California	Hanson Industries	do.	Do.

[1]This table had been table 8 in previous issues of the Minerals Yearbook.

[2]Excludes brines and materials from wells.

[3]Includes industrial sand and gravel. Construction sand and gravel were not available for 1989 because of biennial canvassing.

TABLE 7[1]

TWENTY-FIVE LEADING METAL AND INDUSTRIAL MINERAL[2] MINES IN THE UNITED STATES IN 1989, IN ORDER OF OUTPUT OF TOTAL MATERIALS HANDLED

Mine	State	Operator	Commodity	Mining method
		METALS		
Carlin Mines Complex	Nevada	Newmont Gold Co.	Lode gold	Open pit.
Chino	New Mexico	Phelps Dodge Corp.	Copper	Do.
Goldstrike	Nevada	Barrick Goldstrike Mines Inc.	Lode gold	Do.
Morenci	Arizona	Phelps Dodge Corp.	Copper	Do.
Bingham Canyon	Utah	Kennecot, Utah Copper Corp.	do.	Do.
Smokey Valley Common Operation	Nevada	Round Mountain Gold Corp.	Lode gold	Do.
Tyrone	New Mexico	Phelps Dodge Corp. and Burro Chief Copper Co.	Copper	Do.
Empire	Michigan	Empire Iron Mining Partnership	Iron ore	Do.
Sierrita	Arizona	Cypris Sierrita Corp.	Copper	Do.
Pinto Valley	do.	Pinto Valley Copper Corp.	do.	Do.
Jerritt Canyon (Enfield Bell)	Nevada	Freeport-McMoRan Gold Co.	Lode gold	Do.
Hibbing	Minnesota	Hibbing Taconite Co.	Iron ore	Do.
Erie	do.	LTV Steel Mining Co.	do.	Do.
Mintac	do.	USX Corp.	do.	Do.
Ray	Arizona	ASARCO Incorporated	Copper	Do.
Inspiration	do.	Cyrpus Miami Mining Corp.	do.	Do.
McCoy and Cove	Nevada	Echo Bay Mining Co.	Lode gold	Do.
Tilden	Michigan	Tilden Magnetite Partnership	Iron ore	Do.
Continental	Montana	Montana Resources Inc.	Copper	Do.
Twin Buttes	Arizona	Cyprus Sierrita Corp.	do.	Do.
Sleeper	Nevada	Amax Gold Inc.	Lode gold	Do.
Mission Complex	Arizona	ASARCO Incorporated	Copper	Do.
Mesquite	California	Goldfields Mining Co.	Lode gold	Do.
Candelaria	Nevada	NERCO Metals Inc.	Silver	Do.
Bagdad	Arizona	Cyprus Bagdad Copper Co.	Copper	Do.
		INDUSTRIAL MINERALS[3]		
Lee Creek	North Carolina	Texasgulf Chemical Co.	Phosphate rock	Dredging.
Suwanne	Florida	Occidental Chemical Agricultural Products, Inc.	do.	Open pit
Fort Green	do.	Agrico Chemical Co.	do.	Do.
Fort Meade	do.	Cargill Fertilizer Inc.	do.	Do.
Nichols	do.	Mobil Oil Corp.	do.	Do.
Fort Meade	do.	do.	do.	Do.
Grand Rivers	Kentucky	Reed Crushed Stones Co., Inc.	Stone	Open quarry.
Silver City	Florida	Estech Inc.	Phosphate rock	Open pit.
Hookers	do.	W.R. Grace & Co.	do.	Do.
Calcite	Michigan	Michigan Mineral Associates	Stone	Open quarry.
Swift Creek	Florida	Occidental Chemical Agricultural Products, Inc.	Phosphate rock	Open pit.
Cook	Illinois	General Dynamics Corp.	Stone	Open quarry.
Stoneport	Michigan	Presque Isle Corp.	do.	Do.
McCook	Illinois	Vulcan Materials Co.	do.	Do.
FEC Hialea	Florida	Rinker Materials Corp.	do.	Do.
Pennsuco	do.	Tarmac America Inc.	do.	Dredging.
Beckman	Texas	Redland Stone Products	do.	Open quarry.
White Rock	Florida	Vecellio and Grogan Inc.	do.	Do.
Vernal	Utah	Cheveron Chemical Co.	Phosphate rock	Open pit.
Georgetown	Texas	Texas Crushed Stone Co.	Stone	Open quarry.
St. Genevieve	Missouri	Tower Rock Stone Co.	do.	Do.
New Braunfels	Texas	Parker Bros and Co	do.	Do.
Payne Creek	Florida	Agrico Chemical Co.	Phosphate rock	Open pit.
Oro Grande	California	Riverside Cement Co.	Stone	Open quarry.
Cape Sandy	Indiana	Mulzer Crushed Stone Co., Inc.	do.	do.

[1]This table had been table 9 in previous issues of the Minerals Yearbook.
[2]Excludes brines and materials from wells.
[3]Includes industrial sand and gravel. Construction sand and gravel were not available for 1989 because of biennial canvassing.

TABLE 8[1]

ORE TREATED OR SOLD PER UNIT OF MARKETABLE PRODUCT AT SURFACE AND UNDERGROUND MINES[2] IN THE UNITED STATES IN 1989, BY COMMODITY

Commodity		Surface: Ore treated (thousand short tons)	Surface: Marketable product (units)	Surface: Ratio of units of ore to units of marketable product	Underground: Ore treated (thousand short tons)	Underground: Marketable product (units)	Underground: Ratio of units of ore to units of marketable product	Total[3]: Ore treated (thousand short tons)	Total[3]: Marketable product (units)	Total[3]: Ratio of units of ore to units of marketable product
METALS										
Bauxite	thousand long tons	951	673	1.4:1	—	—	—	951	673	1.4:1
Copper	thousand short tons	286,000	1,520	188.8:1	4,770	85	56.4:1	291,000	1,600	181.8:1
Gold:										
Lode	thousand troy ounces	169,000	6,820	24.8:1	16,600	412	40.2:1	186,000	7,230	25.7:1
Placer	do.	13,800	190	72.5:1	—	—	—	13,800	190	72.5:1
Iron ore	thousand long tons	224,000	56,300	4.0:1	W	W	—	224,000	56,300	4.0:1
Lead	thousand short tons	W	W	—	8,590	269	31.9:1	8,590	269	31.9:1
Silver	do.	12,900	11,300	1.1:1	3,770	17,300	.2:1	16,700	28,600	.6:1
Zinc	do.	—	—	—	5,490	174	31.5:1	5,490	174	31.5:1
INDUSTRIAL MINERALS										
Abrasives[4]	thousand short tons	87	87	1.0:1	W	W	—	87	87	1.0:1
Barite	do.	320	320	1.0:1	—	—	—	320	320	1.0:1
Clays	do.	58,400	45,600	1.3:1	270	240	1.1:1	58,700	45,800	1.3:1
Diatomite	do.	1,290	641	2.0:1	—	—	—	1,290	641	2.0:1
Feldspar	do.	721	695	1.0:1	—	—	—	721	695	1.0:1
Gypsum	do.	16,400	15,600	1.1:1	1,670	1,670	1.0:1	18,100	17,300	1.0:1
Iron oxide pigments (crude)	do.	35	34	1.0:1	—	—	—	35	34	1.0:1
Mica (scrap)	do.	219	99	2.2:1	—	—	—	219	99	2.2:1
Perlite	do.	1,310	597	2.2:1	W	W	—	1,310	597	2.2:1
Phosphate rock	do.	210,000	51,800	4.0:1	W	W	—	210,000	51,800	4.0:1
Potash	do.	W	W	—	969,000	969,000	1.0:1	969,000	969,000	1.0:1
Pumice[5]	do.	469	467	1.0:1	—	—	—	469	467	1.0:1
Salt	do.	4,320	830	5.2:1	12,800	12,600	1.0:1	17,100	13,400	1.3:1
Sand and gravel	do.	33,000	29,200	1.1:1	—	—	—	33,000	29,200	1.1:1
Soda ash	do.	—	—	—	16,300	8,980	1.8:1	16,300	8,980	1.8:1
Stone:										
Crushed and broken	do.	1,190,000	1,190,000	1.0:1	30,300	30,300	1.0:1	1,220,000	1,220,000	1.0:1
Dimension	do.	3,470	1,170	3.0:1	W	W	—	3,470	1,170	3.0:1
Talc, soapstone, and pyrophyllite	do.	1,420	1,170	1.2:1	W	W	—	1,420	1,170	1.2:1
Vermiculite	do.	307	293	1.0:1	—	—	—	307	293	1.0:1

W Withheld to avoid disclosing company proprietary data.
[1]This table had been table 10 in previous issues of the Minerals Yearbook.
[2]Excludes wells, ponds, and pumping operations.
[3]Data may not add to totals shown because of independent rounding.
[4]Includes abrasive stone and millstones.
[5]Excludes volcanic cinder and scoria.

TABLE 9[1]

MATERIAL HANDLED PER UNIT OF MARKETABLE PRODUCT AT SURFACE AND UNDERGROUND MINES[2] IN THE UNITED STATES IN 1989, BY COMMODITY

Commodity		Surface: Total material handled[4] (thousand short tons)	Surface: Marketable product (units)	Surface: Ratio of units of material handled to units of marketable product[5]	Underground: Total material handled[4] (thousand short tons)	Underground: Marketable product (units)	Underground: Ratio of units of material handled to units of marketable product[5]	Total[3]: Total material handled[4] (thousand short tons)	Total[3]: Marketable product (units)	Total[3]: Ratio of units of material handled to units of marketable product[5]
METALS										
Bauxite	thousand long tons	5,360	673	8.0:1	—	—	—	5,360	673	8.0:1
Copper	thousand short tons	634,000	1,520	418.1:1	4,880	85	57.7:1	639,000	1,600	399.1:1
Gold:										
Lode	thousand troy ounces	780,000	6,820	114.4:1	15,600	412	40.1:1	796,000	7,230	110.2:1
Placer	do.	40,500	190	212.8:1	—	—	—	40,500	190	212.8:1
Iron ore	thousand long tons	314,000	56,300	5.6:1	W	W	—	314,000	56,300	5.6:1
Lead	thousand short tons	W	W	—	8,860	269	32.9:1	8,860	269	32.9:1
Silver	do.	48,400	12,300	4.3:1	4,210	17,300	2:1	52,700	28,600	1.8:1
Zinc	do.	—	—	—	5,740	174	32.9:1	5,740	174	32.9:1
INDUSTRIAL MINERALS										
Abrasives[6]	thousand short tons	203	87	2.3:1	W	W	—	203	87	2.3:1
Barite	do.	320	320	1.0:1	—	—	—	320	320	1.0:1
Clays	do.	109,000	45,600	2.4:1	274	240	1.1:1	109,000	45,800	2.4:1
Diatomite	do.	736	641	1.1:1	—	—	—	736	641	1.1:1
Feldspar	do.	721	695	1.0:1	—	—	—	721	695	1.0:1
Gypsum	do.	27,400	15,600	1.8:1	1,680	1,670	1.0:1	29,100	17,300	1.7:1
Iron oxide pigments (crude)	do.	31	359:1	—	—	—	31	359:1		
Mica (scrap)	do.	317	99	3.2:1	—	—	—	317	99	3.2:1
Perlite	do.	1,040	597	1.7:1	W	W	—	1,040	597	1.7:1
Phosphate rock	do.	579,000	51,800	11.2:1	W	W	—	579,000	51,800	11.2:1
Potash	do.	W	W	—	969	969	1.0:1	969	969	1.0:1
Pumice[7]	do.	617	467	1.3:1	—	—	—	617	467	1.3:1
Salt	do.	4,330	830	5.2:1	12,800	12,600	1.0:1	17,200	13,400	1.3:1
Sand and gravel	do.	33,300	29,200	1.1:1	—	—	—	33,300	29,200	1.1:1
Soda ash	do.	—	—	—	18,500	8,980	2.1:1	18,500	8,980	2.1:1
Stone:										
Crushed and broken	do.	1,290,000	1,190,000	1.1:1	30,500	30,300	1.0:1	1,320,000	1,220,000	1.1:1
Dimension	do.	4,900	1,170	4.2:1	W	W	—	4,900	1,170	4.2:1
Talc, soapstone, and pyrophyllite	do.	6,200	1,170	5.3:1	W	W	—	6,200	1,170	5.3:1
Vermiculite	do.	W	W	—	—	—	—	W	W	—

W Withheld to avoid disclosing company proprietary data.
[1]This table had been table 11 in previous issues of the Minerals Yearbook.
[2]Excludes wells, ponds, and pumping operations.
[3]Data may not add to totals shown because of independent rounding.
[4]Includes material from exploration and development activities.
[5]Material from development and exploration activities is excluded from the ratio calculation.
[6]Includes abrasive stone and milltones.
[7]Excludes volcanic cinder and scoria.

TABLE 10[1]

MINING METHODS USED IN OPEN PIT MINING IN THE UNITED STATES, BY COMMODITY

(Percent)

Commodity	Total material handled: Preceded by drilling and blasting	Total material handled: Not preceded by drilling and blasting[2]
METALS		
Bauxite	100	—
Beryllium	—	100
Copper	96	4
Gold:		
Lode	98	2
Placer	—	100
Iron ore	97	3
Magnesium	100	—
Mercury	100	—
Molybdenum	100	—
Silver	100	—
Tin	—	100
Titanium (ilmenite)	—	100
Tungsten	—	100
INDUSTRIAL MINERALS		
Abrasives[3]	57	43
Aplite	100	—
Asbestos	100	—
Barite	100	—
Boron	100	—
Clays	100	—
Diatomite	99	1
Feldspar	100	—
Graphite	100	—
Gypsum	92	8
Iron oxide pigments (crude)	100	—
Kyanite	100	—
Magnesite	100	—
Marl (greensand)	100	—
Mica (scrap)	28	72
Olivine	100	—
Perlite	70	30
Phosphate rock	3	97
Potash	—	100
Pumice[4]	87	13
Pyrite	100	—
Salt	—	100
Sand and gravel	11	89
Stone:		
Crushed and broken	99	1
Dimension	—	100
Talc, soapstone, and pyrophyllite	100	—
Vermiculite	100	—
Average[5]	89	11

[1]This table had been table 12 in previous issues of the Minerals Yearbook.
[2]Includes drilling or cutting without blasting, dredging, or mechanical excavation and nonfloat washing, and other surface mining methods.
[3]Includes abrasive stone and millstones.
[4]Excludes volcanic cinder and scoria.
[5]Includes unpublished data.

TABLE 11[1]

EXPLORATION AND DEVELOPMENT ACTIVITY IN THE UNITED STATES IN 1989, BY METHOD, COMMODITY, AND STATE

(Feet)

Commodity	Exploration							Development				
	Churn drilling	Diamond drilling	Percussion drilling	Rotary drilling	Other drilling	Trench-ing	Total[2]	Drifting, cross-cutting, or tunneling	Raising	Shaft and winze sinking	Solution mining	Total[2]
METALS												
Copper	—	63,300	66,000	W	—	—	129,000	8,730	158	2	—	8,890
Gold:												
Lode	W	554,000	626,000	2,040,000	266,000	50,600	3,540,000	702,000	12,700	1,120	—	716,000
Placer	—	—	—	W	50,300	115	50,400	—	—	—	—	—
Iron ore	W	23,500	—	—	—	—	23,500	W	—	—	—	—
Lead	W	W	W	30	13,100	—	13,100	16,500	1,610	—	—	18,100
Platinum-group metals	—	50,900	—	—	—	—	50,900	W	W	—	—	—
Silver	—	63,200	W	W	12	—	63,200	27,100	4,240	176	—	31,500
Titanium concentrates	—	1,500	3,000	—	—	—	4,500	—	—	—	—	—
Other[3]	82,800	62,400	454,000	138,000	38,800	—	777,000	84,100	7,780	—	—	91,900
Metals total[2]	82,800	819,000	1,150,000	2,180,000	368,000	50,700	4,650,000	839,000	26,500	1,300	—	867,000
Percent of metals total[4]	1.8	17.6	24.7	46.9	7.9	1.1	100.0	96.8	3.1	.2	—	100.0
INDUSTRIAL MINERALS												
Diatomite	—	660	—	W	—	—	660	—	—	—	—	—
Gypsum	—	1,720	—	W	—	—	1,720	—	—	—	—	—
Perlite	—	1,260	—	W	—	500	1,760	—	—	—	—	—
Phosphate rock	—	W	—	76,300	—	—	76,300	W	W	—	—	—
Pumice[5]	—	20	—	2,900	—	—	2,920	—	—	—	—	—
Stone (crushed and broken)	—	943	—	—	—	—	943	—	—	—	—	—
Talc, soapstone, and pyrophyllite	—	—	—	—	511	—	511	—	—	—	—	—
Other[6]	644	76,300	32,600	223,000	52,300	305	385,000	168,000	1,530	—	—	169,000
Industrial minerals total[2]	644	80,900	32,600	302,000	52,800	805	470,000	168,000	1,530	—	—	169,000
Percent of industrial minerals total[4]	.1	17.2	6.9	64.3	11.2	.2	100.0	99.1	.9	—	—	100.0
Grand total[2]	83,500	900,000	1,180,000	2,480,000	420,000	51,500	5,120,000	1,010,000	28,000	1,300	—	1,040,000
Percent of grand total[4]	1.6	17.6	23.1	48.5	8.2	1.0	100.0	97.2	2.7	.1	—	100.0
STATE												
Alaska	—	W	3,000	W	32,200	40,100	75,300	W	—	—	—	—
Arizona	—	W	—	W	—	—	0	4,350	882	—	—	5,230
Arkansas	—	1,930	—	3,210	—	—	5,140	—	—	—	—	—
California	—	5,640	26,400	120,000	W	4,360	156,000	2,680	W	600	—	3,280
Colorado	W	140,000	W	102,000	200	W	242,000	29,300	4,460	3	—	33,700
Florida	—	—	—	36,700	—	—	36,700	—	—	—	—	—
Idaho	—	W	150	W	15,100	—	15,200	24,400	3,470	W	—	27,800
Minnesota	W	22,700	—	—	—	—	22,700	—	—	—	—	—
Montana	—	88,700	110,000	82,200	W	W	281,000	33,500	4,390	—	—	37,900
Nevada	W	199,000	557,000	1,610,000	221,000	5,250	2,590,000	168,000	W	90	—	169,000
New Mexico	W	2,160	11,400	4,440	36,800	—	54,800	W	W	—	—	—
Oregon	—	31,900	19,000	W	—	—	50,900	1,520	158	20	—	1,690

See footnotes at end of table.

TABLE 11[1]—Continued

EXPLORATION AND DEVELOPMENT ACTIVITY IN THE UNITED STATES IN 1989, BY METHOD, COMMODITY, AND STATE

(Feet)

Commodity	Exploration: Churn drilling	Diamond drilling	Percussion drilling	Rotary drilling	Other drilling	Trenching	Total[2]	Development: Drifting, crosscutting, or tunneling	Raising	Shaft and winze sinking	Solution mining	Total[2]
STATE—Continued												
South Dakota	—	60,000	11,000	75,000	7,280	—	153,000	524,000	5,800	—	—	529,000
Utah	—	4,960	W	42,200	13,900	1,300	62,400	W	W	—	—	—
Undistributed[7]	83,500	343,000	445,000	409,000	94,100	515	1,370,000	219,000	8,880	588	—	228,000
Total all States[2]	83,500	900,000	1,180,000	2,480,000	420,000	51,500	5,120,000	1,010,000	28,000	1,300	—	1,040,000
Percent of all States[4]	1.6	17.6	23.1	48.5	8.2	1.0	100.0	97.2	2.7	.1	—	100.0

W Withheld to avoid disclosing company proprietary data; included with "Other."
[1]This table has been table 13 in the previous issue of the Minerals Yearbook.
[2]Data may not add to totals shown because of independent rounding.
[3]Includes antimony, beryllium, molybdenum, rare-earth concentrates, zinc, and metals items indicated by symbol W.
[4]Based on unrounded footage.
[5]Excludes volcanic cinder and scoria.
[6]Includes abrasives, boron minerals, fluorspar, gypsum, lime, soda ash, stone (dimension), and mineral items indicated by symbol W.
[7]Includes Illinois, Michigan, Missouri New York, Oklahoma, South Carolina, Virginia, Washington, Wyoming, and State items indicated by symbol W.

TABLE 12[1]

TOTAL MATERIAL (ORE AND WASTE) PRODUCED BY MINE DEVELOPMENT IN THE UNITED STATES IN 1989, BY COMMODITY AND STATE

(Thousand short tons)

	Drifting, crosscutting, or tunneling	Raising	Shaft and winze sinking	Stripping	Total[2]
METALS					
Copper	145	(3)	(3)	2	148
Gold:					
Lode	3,020	82	10	75,600	78,700
Placer	—	—	—	12,500	12,500
Lead	286	16	—	—	302
Silver	429	213	2	—	645
Others[4]	554	20	—	8,940	9,510
Metals total[2]	4,430	332	13	97,000	102,000
INDUSTRIAL MINERALS					
Abrasives[5]	—	—	—	34	34
Others[6]	2,190	(3)	—	11,900	14,100
Industrial minerals total[2]	2,190	(3)	—	11,900	14,100
Grand total[2]	6,620	332	13	109,000	116,000
STATE					
Alaska	W	—	—	10,100	10,100
Arizona	78	3	—	4	86
California	8	W	1	2,890	2,900
Colorado	139	16	(3)	—	155
Idaho	413	210	W	203	826
Montana	112	22	—	—	134
Nevada	593	W	1	70,300	70,900
New Mexico	W	W	—	30	30
Oregon	6	(3)	(3)	W	7
South Dakota	2,400	22	—	—	2,430
Utah	W	W	—	8,400	8,400
Undistributed[7]	2,870	58	10	17,100	20,000
Total[2]	6,620	332	13	109,000	116,000

W Withheld to avoid disclosing company proprietary data; included with "Other" or "Undistributed."
[1]This table had been table 14 in the previous issue of the Minerals Yearbook.
[2]Data may not add to total shown because of independent rounding.
[3]Less than 1/2 unit.
[4]Includes iron ore, molybdenum, platinum-group metals, and zinc.
[5]Includes abrasive stone and millstones.
[6]Includes fluorspar, gypsum, phosphate, pumice, soda ash, and talc and pyrophyllite.
[7]Includes Illinois, Michigan, Minnesota, Missouri, New York, Oklahoma, Tennessee, Washington, Wyoming, and State items indicated by symbol W.

TABLE 13[1]

INDUSTRIAL EXPLOSIVES AND BLASTING AGENTS SOLD FOR CONSUMPTION IN THE UNITED STATES, BY CLASS AND USE

(Thousand pounds)

Year	Coal mining	Metal mining	Quarrying and nonmetal mining	Total mineral industry	Construction work	All other purposes	Total industrial[2]
			TOTAL, BY USE				
1985	2,241,303	382,410	510,500	3,134,213	247,451	418,690	3,800,354
1986	2,566,337	319,844	585,220	3,471,401	258,651	192,784	3,922,836
1987	3,220,762	340,283	482,911	4,043,956	308,912	145,389	4,498,257
1988[e]	3,137,000	440,000	595,250	4,172,250	320,200	245,000	4,737,440
1989[e]	3,175,000	480,000	630,210	4,285,210	330,170	190,000	4,805,380
			BY CLASS AND USE PERMISSIBLES				
1985	[3]34,563	[3]117	[3]481	35,161	[3]836	[4]71	36,068
1986	34,971	7	[3]155	35,133	245	[4]61	35,439
1987	33,391	—	248	33,639	214	—	33,853
1988[e]	27,000	—	250	27,250	200	—	27,450
1989[e]	22,000	—	210	22,210	170	—	22,380
			OTHER HIGH EXPLOSIVES				
1985[5]	[3]21,705	[3]9,466	[3]55,470	86,641	[3]35,460	[4]13,775	135,876
1986	18,004	7,027	[3]63,249	88,280	37,403	[4]6,106	131,789
1987	23,171	9,013	62,250	94,434	43,355	5,458	143,247
1988[e]	20,000	10,000	65,000	95,000	45,000	10,000	150,000
1989[e]	19,000	9,000	61,000	89,000	42,000	9,000	140,000
			WATER GELS AND SLURRIES				
1985[5]	[3]133,858	[3]66,653	[3]80,283	280,794	[3]27,487	[4]16,245	324,526
1986	180,201	57,153	[3]128,854	366,208	38,582	[4]15,300	420,090
1987	195,737	63,125	160,412	419,274	55,758	6,326	481,358
1988[e]	240,000	100,000	220,000	560,000	80,000	20,000	660,000
1989[e]	234,000	98,000	215,000	547,000	78,000	20,000	645,000
			AMMONIUM NITRATE: FUEL OIL BLASTING AGENTS AND UNPROCESSED				
1985[6]	[3]2,051,177	[3]306,174	[3]374,266	2,731,617	[3]183,668	[4]388,599	3,303,884
1986	2,333,161	255,657	[3]392,962	2,981,780	182,421	[4]171,317	3,335,518
1987	2,968,463	268,145	260,001	3,496,609	209,585	133,605	3,839,799
1988[e]	2,850,000	330,000	310,000	3,490,000	195,000	215,000	3,899,990
1989[e]	2,900,000	373,000	354,000	3,627,000	210,000	161,000	3,998,000

[e]Estimated.

[1]This table had been table 15 in the previous issue of the Minerals Yearbook.

[2]Data may not add to totals shown because of independent rounding.

[3]Some quantities of this use are included with "All other purposes" to avoid disclosing company proprietary data.

[4]Includes some quantities from "Coal mining," "Metal mining," "Quarrying and nonmetal mining," and "Construction work."

[5]Some quantities of this use are included with "Ammonium nitrate: Fuel oil blasting agents and unprocessed" to avoid disclosing company proprietary data.

[6]Includes some quantities from "Other high explosives," and "Water gels and slurries."